NUCLEONICS

A McGRAW-HILL PUBLICATION ★ SEVENTY-FIFTH ISSUE

I look for a very substantial activity in tagged-atom experimentation in industry. It is conceivable that many industrial processes can be eventually controlled by the use

The field of instruments relating to nucleonics will be very large. The need for instruments in this field is, perhaps, greater than that of any other so far uncovered by man. Not only will these instruments be

Pile development is only in its infancy. In the future there will be need for large piles and small piles, for low-temperature piles and for high-temperature piles, for high-output piles and for low-output piles. There will be need for the dissipation of a maximum amount of energy

it is seen that the value of power is not a fixed thing, and it may be that many uses will be found for pile power in which the overall cost of the power is not the controlling factor. On the other hand, we should not conclude that the cost of

Let us consider some aspects of the power situation. It might be possible to put in power plants in the far north or in desert regions adjacent to important mineral deposits. Other sources of power might be practically unavailable in

be true in connection with airplanes, electronics, and in many other activities. If the United States unduly restricts scientific and industrial activities in nucleonics, and other countries do not, such other countries should eventually have a military advantage over us. It is, therefore, of vital

Words of Prophecy

★ *Events of past decade bear out promise of growth of atomic energy industry that was predicted July 13, 1944...* *see page 8*

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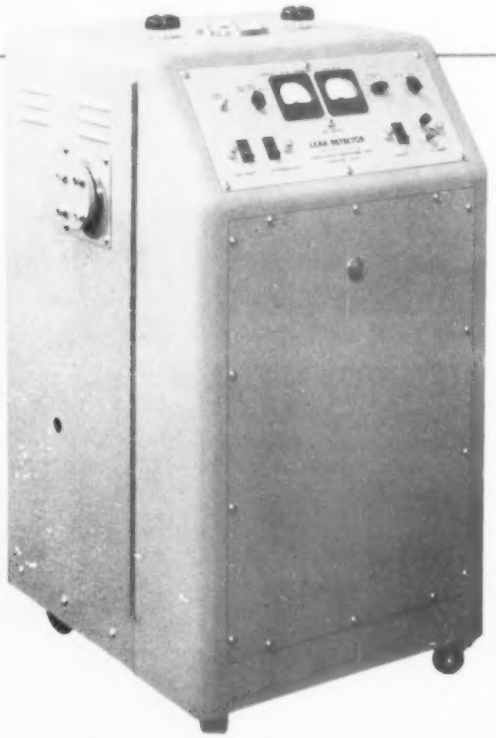

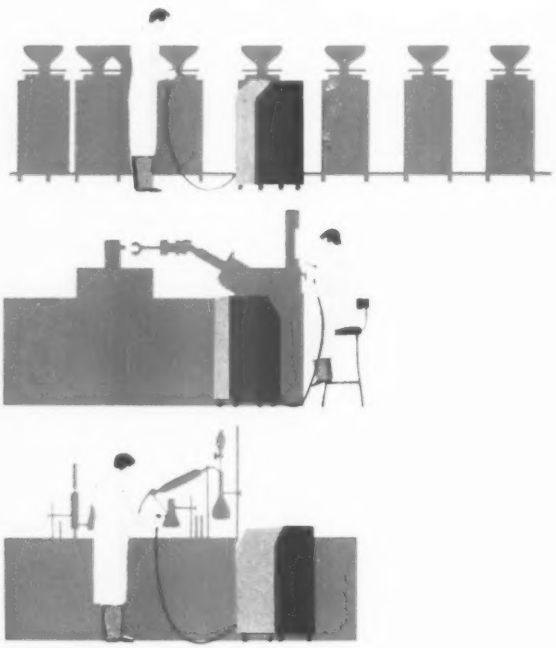

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NUCLEONICS

JULY • 1954

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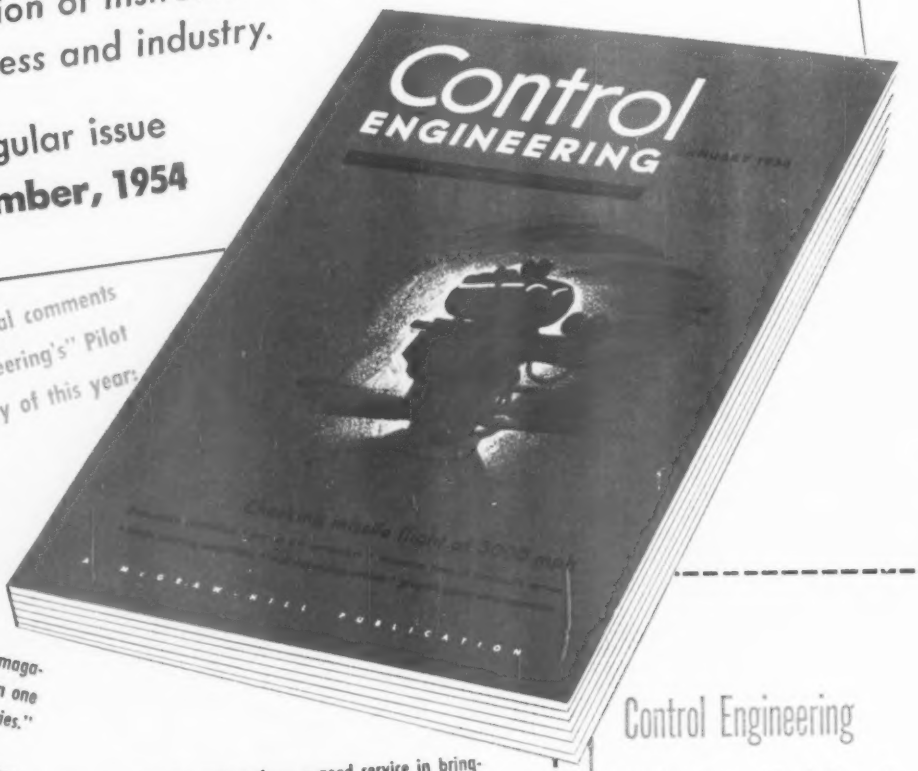

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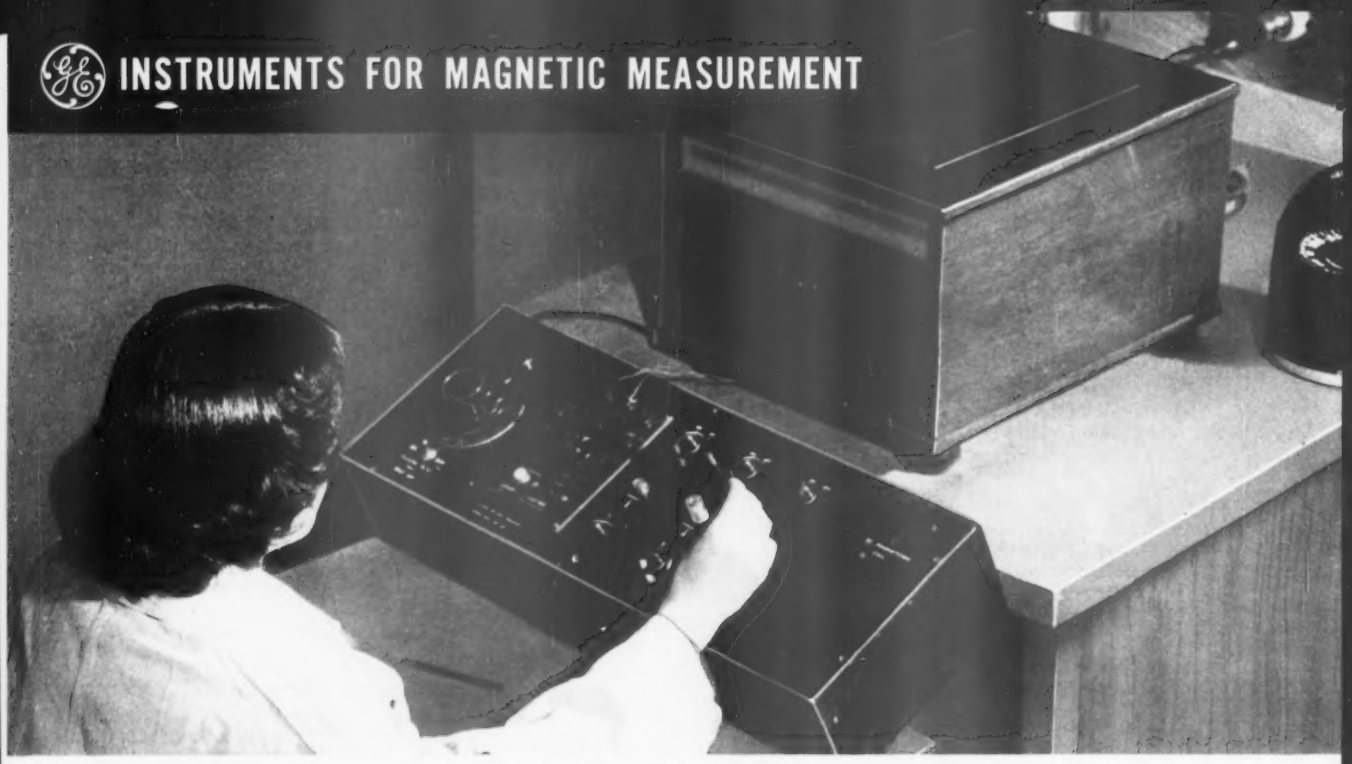

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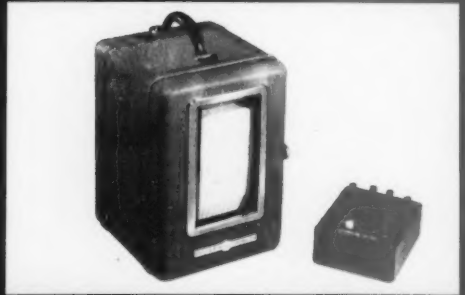

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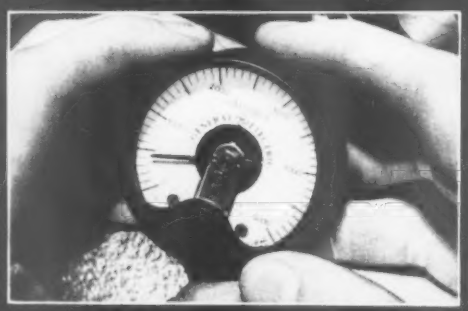

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GENERAL ELECTRIC

LATE NEWS

Compiled by NUCLEONICS June 28 . . . for publication July 2

International Atom First major international nuclear engineering conference in this country sponsored by American Institute of Chemical Engineers, was held last week at Ann Arbor, Mich. Nearly 120 foreign scientists and program officials representing 16 nations were present. Although some newly declassified information was presented, foreigners particularly noticed secrecy barriers.

•

Belgian Reactor Construction has begun on Belgium's first reactor—a 3½-Mw graphite-moderated reactor using U. S.-fabricated natural-uranium fuel elements. The Belgians changed their plans last year when they were able to get 30 tons of canned fuel slugs from this country and sufficient graphite from Britain to permit building a larger reactor patterned after the air-cooled Oak Ridge pile. In Parliament, the former Belgian foreign minister reported the fuel and graphite came from "our Anglo-American allies." For diplomatic reasons the U. S. has tried to keep the transfer quiet.

•

Canadian Shift Reorganization of Canada's nuclear activities would put Chalk River research and Eldorado uranium mining operations under a single crown holding company. Under the new set-up Chalk River operations would be under Nuclear Research Ltd., with Atomic Energy of Canada Ltd. becoming the holding company name. Chief purpose is to plow mining profits into nuclear research at the Chalk River project.

•

Dutch-Norwegian Reactor Holland and Norway may combine on another reactor project. The Dutch Parliament has been asked to authorize construction of a $7.4-million pressurized heavy-water reactor that would produce 10,000 kw and be the prototype for a merchant ship plant. The reactor would be built in Holland, with the cost borne by the Dutch and the Norwegians supplying the fuel.

•

Argentine Plans Mystery surrounding Argentine atomic energy program has obscured active work in progress for past several years. Plans are now jelling for Argentina's first nuclear reactor. Patterned partially after now-defunct Daniels Oak Ridge design concept, it will be natural-uranium fueled, beryllium-oxide moderated, heavy-water cooled, and will produce 17,000 kw.

•

Research Money Congress has just approved fiscal '55 money for: high-performance research reactor—for Oak Ridge, to produce 10,000 kw and 10^{14}n/cm²/sec—cost: 2½-million; strong-focusing synchrotron for Brookhaven—cost: $20 million; pilot plant for processing gross fission products—cost: $1½-million—and new physics of solid state building, both at Oak Ridge.

•

European Nuclear Society Federal atomic energy agencies in eight European nations have formed the European Atomic Society with Sir John Cockcroft of Britain as president and Gunnar Randers of Norway as executive vice president. In addition to holding meetings and sponsoring publications, the group is already planning standardization activities and will sponsor research.

•

Rockies Study Team Electric power and other industries in the Rocky Mountain area are making plans to contract with the AEC for a new nuclear power study team.

LATE NEWS (Continued)

AEC Budget Total AEC '55 budget sent to the President by Congress is $1.2-billion with $1.1 billion for operations and $0.1-billion for plant and equipment. Operating expenses include $1.8-million for physical research and $0.4-million for biology and medicine.

•

Nuclear Aircraft The Navy is now in the slow-paced race for a nuclear-propelled aircraft. Navy Bureau of Aeronautics has let contracts to Consolidated Vultee and Glenn L. Martin to research on seaplane frames suitable for nuclear-powered flight. Air Force program is now oriented on long-range schedule, away from concept of merely trying to get something into the air.

•

Rural Atom Rural electrification administration is considering a study of feasibility of atomic power plants for farm electric systems. Idea is to see whether a nuclear power plant could be adapted to rural load requirements on an economic basis. The Senate urged the study and tentatively earmarked $20,000 to finance it during the next fiscal year.

•

Revision of Law Down the home stretch the big revisions in the Atomic Energy Act are racing against time. With Congressional adjournment now tentatively set for around July 31, the long, complicated measure must still clear both houses of Congress.

Backers of the bill, with fingers crossed, predict success, but admit either of two issues could upset the chances of passage. Potential traps are: (1) The Oppenheimer security-risk case. (2) The AEC-Tennessee Valley Authority electric power purchase contracts.

Neither of these have a vital bearing on crucial language in the measure, main purposes of which are to encourage industrial development of atomic power and permit exchange of information and nuclear material with our allies. However, because of the wide public interest and politics involved in these two issues, opponents of the measure could use them to divert attention from the main purposes of the bill and tie up a final vote.

As the Joint Congressional Committee on Atomic Energy went into their last series of closed sessions on the measure a mood of compromise was evident. Still to be threshed out as NUCLEONICS went to press were several of the provisions in the general licensing section of the bill.

Compromises on controversial sections of the bill were shaping up along these lines:

1. AEC organization—The Chairman would be spokesman and preside at meetings of the commission, but otherwise have no authority beyond that shared with the four other members.

2. Patents—Compulsory licensing for basic patents in the atomic power field seemed assured for a limited time and on a carefully prescribed basis.

3. AEC information—The committee was ready to drop proposed fines aimed at publishers, reporters and others for relaying atomic information that might possibly be restricted.

4. Foreign exchange—The committee appeared satisfied with the criteria set out in earlier versions of the bill for sharing information and nuclear material with friendly foreign nations. Passage of this part of bill is of real significance to U. S.-Belgium relations. Agreement by which we get uranium from them is up for extension this year. (In addition to enriched fissionable materials, the Belgians would like access to U. S. pressurized water reactor technology to prepare them for a second reactor they are planning.)

5. Licensing—Provisions for licensing of industrial firms will probably be spelled out to require AEC to guard against development of monopoly in issuance of licenses.

NUCLEONICS JULY, 1954

Jerome D. Luntz, *Editor*

Adspice, Respice, Prospice

IN ADDITION TO BEING FUN, crystal ball gazing frequently facilitates our setting our sights on the future. It is with this in mind that we are publishing the historical letter on pgs. 8–10. Written in 1944, the letter contains many predictions that have already been realized. More interesting, however, are those predictions that are yet to be proven true but may well be. To place his letter in better present-day perspective, the author—Zay Jeffries—has passed on the following thoughts:

"The surface of the nucleonics field has barely been scratched. We are now witnessing the early beginnings of a tidal wave of nucleonic activity, the future velocity and extent of which no one can predict. Suffice it to say that the tempo will be fast in comparison with other great historical movements, the extent will be vast, it will be unbelievably complex and the duration will be determined by the life of civilization itself.

"Will nucleonics shorten the life of our civilization? I believe not. The Constitution of the United States was not the result of a happy inspiration. It represented the concentrated wisdom of our founding fathers gained by living for decades with knotty problems requiring resolution. We are now living in the midst of another group of knotty problems created in part by the advent of nucleonics. If the world will concentrate on making nucleonics work *for* civilization, it will in due course be apparent that a new tool for solving man's problems has been created.

"Will the present and coming generations be equal to the challenge? I believe they will—again not by any happy inspiration but by living intimately with the problems and forging out the right answers on the anvil of experience. No one will suggest that this is an easy task. It is, however, a necessary one and man has a long record of solving the problems incident to his survival."

AS IF TO BEAR Mr. Jeffries out, the Atomic Energy Commission came out last month with a very optimistic long-range view of the impact of atomic energy upon our economy. Because its analysis is based on a hard look into its crystal ball and because it is the most authoritative crystal ball viewer in the world, we present here, in detail, a summary of AEC's predictions.

AEC first says that the probability of achieving 4–7 mill/kwh nuclear power is good. On this basis, it says "a variety of economic and social benefits" will result, "some of which may be striking individually and all of which would be significant taken together." These benefits are:

"Nuclear power may help make it possible to undertake large new industrial activities at sites that would otherwise be uneconomic in the face of punishing transportation charges or the absence of transport facilities for conventional fuels.

"It may provide an economic solution to the problem of providing additional cheap electric energy in locations where the demand is expected to outrun the availability of hydroelectric power and fossil fuels are lacking.

"It may permit and perhaps encourage the development of stratetically decentralized areas of industrial production requiring low-cost electric energy.

"It may provide blocks of electric energy for government and military installations where the cost of power is important, but not controlling in site selection.

"It may help electric utility systems in metropolitan areas to adjust to such limiting factors as rail transportation and smoke nuisance arising from a major increase in electric energy generation from coal.

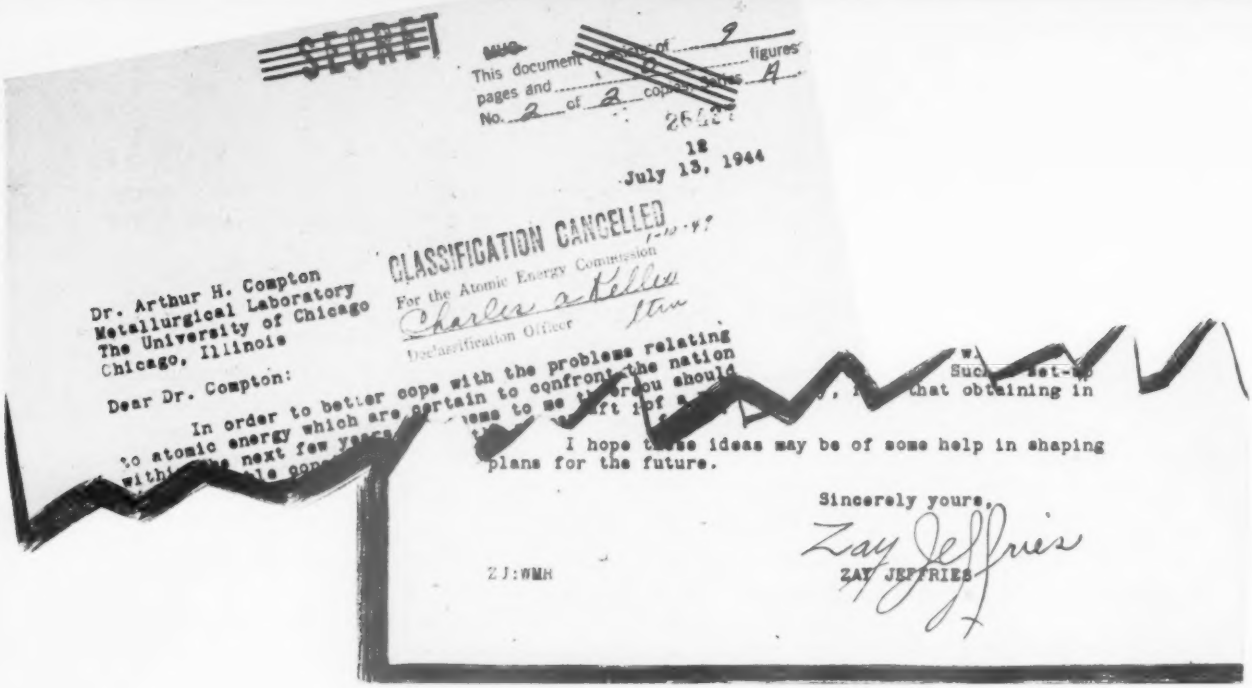
"It may contribute in some measure to the introduction of new production techniques in electroprocess industries.

"It may become technically feasible and economic for commercial propulsion purposes, such as for powering merchant ships.

"It will take on increasing importance as a strong force both in holding down energy costs as exhaustible resources are used up and in assuring the availability of fuel for continued economic growth.

"It may stimulate consumption of electricity beyond present projections and accelerate the trend toward using a larger portion of our energy in the form of electricity.

"A sound basis will be established for assisting other nations in applying nuclear power for economic development."



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July 13, 1944

CLASSIFICATION CANCELLED
For the Atomic Energy Commission
Declassification Officer

Dr. Arthur H. Compton
Metallurgical Laboratory
The University of Chicago
Chicago, Illinois

Dear Dr. Compton:

In order to better cope with the problems relating to atomic energy which are certain to confront the nation within the next few years, it seems to me that you should give favorable consideration to the preparation of a prospectus of this field . . . your group is in as good position as any to speculate . . .

From laboratory experiments a few decades ago electronics has evolved into one of the most lusty of the sciences and industries. Billions of dollars are being spent for electronic devices for war. The field seems to be headed for great post-war developments.

Does not the nuclear field look as promising now as electronics did, say, thirty years ago? I believe it looks more promising.

I will use the word "nucleonics" as a name for this field for the purposes of this letter . . . "Nucleonics" is suggested because the nucleus of the atom is not composed of a single kind of particle. *Nucleon* could be used as a generic term to mean either a neutron or a proton or, if preferable, to include heavier aggregates such as the alpha particle nucleus . . .

While the number of instruments, such as cyclotrons, high-voltage X-rays, and piles, may be limited for a considerable time to come, there are many opportunities for researchers to work in this field with small outlay of capital for equipment and supplies . . . anyone with some radium and beryllium can carry on certain nuclear physics experiments, and anyone with a little uranium or thorium can carry on chemical experiments which relate to nucleonics. Also, anyone with X-rays or radium can carry on work in connection with health or safety matters.

It will be impossible to stop the scientific world from tackling the whole nucleonics scientific field feverishly in the post-war period . . . In my opinion, this will apply to universities, private laboratories, government laboratories, and industrial laboratories . . .

The use of elements exhibiting artificial radioactivity may be expected to be large and varied . . . Not only will tagged-atom experiments be needed by the thousands on human beings themselves, but they will be needed also for study in other animals and organisms and in plants . . . Such experiments will also be useful in connection with underground water flow, the movement of air, etc.

I look for a very substantial activity in tagged-atom experimentation in industry. It is conceivable that many industrial processes can be eventually controlled by the use of tagged atoms. It is probable also that much new information in industry will come as a result of these studies . . .

Other things come to mind, such as the

I hope these ideas may be of some help in shaping plans for the future.

Sincerely yours,

Zay Jeffries

ZJ:WMH

ZAY JEFFRIES

anticipated McMahon act debate

small nations all over the world have important atomic activity on small budgets

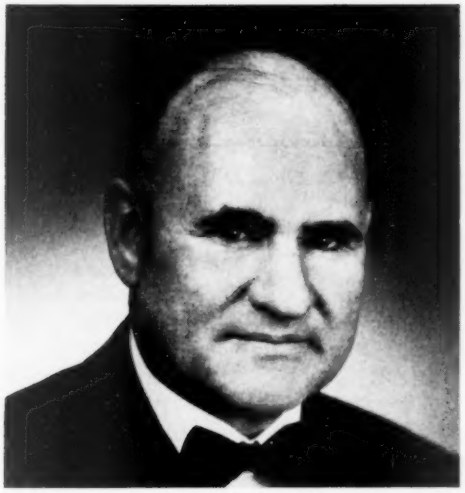
- Electronics: '54 - $300 million '54 - $6 billion
- Nucleonics: '54 $25 million '84 $1.2 billion

much work on oil flow in pipes; some on underground water; bomb-produced radioactivity used for meteorological studies

birth of name of NUCLEONICS magazine

Industry largest radioisotope user group in '53

In the turmoil of the wartime atomic bomb project, a consultant of the Manhattan District took time out to write this then-secret prophetic letter on the peacetime potential of the atom. On this 10th anniversary of the writing of this letter, NUCLEONICS is publishing it both for historical interest and to provide perspective for the future. Marginal notes are editor's comments



Zay Jeffries entered the atomic energy field in 1943 as special adviser to Arthur H. Compton, director of Metallurgical Project of Manhattan District. During the war, he also served the National Research Council as vice chairman of the War Metallurgy Committee and as chairman of the Metals Conservation and Substitution Group of the advisory board on metals and minerals. From 1945 to 1949, Dr. Jeffries, who is now retired, was vice president in charge of the General Electric chemistry department. He still is a consultant for AEC's Hanford Works

minute fraction of a second to hundreds of years. It is likely that many combinations of these rates of consumption will be found useful in the longer future . . .

It would seem at the moment that the piles would be the logical devices for the making of artificial radioactive substances in quantity and at relatively low cost. It would also seem that the pile is the logical device for the development of power. While there can be very little question at the moment about the widespread use of artificial radioactive substances for experimentation and utilization, there may be more question about the ultimate use of piles for power. It seems to me that at this stage we should err on the side of optimism in connection with the future use of piles for power.

over 42,700 shipments of radioisotopes from Oak Ridge up to Dec '53

. . . the value of power is not a fixed thing, and it may be that many uses will be found for pile power in which the over-all cost of the power is not the controlling factor. On the other hand, we should not conclude that the cost of pile power is necessarily going to be high as compared with other power sources . . .

The pile is a device, however, which may produce at least three things of value to mankind: (a) Artificial radioactive elements; (b) Power or energy; and, (c) New products such as 49 or 23*. If all three of these things are useful, then it would seem that the pile may become a device so important that nothing will be able to compete with it.

Such applications are now assumed

Let us consider some aspects of the power situation. It might be possible to put in power plants in the far north or in desert regions adjacent to important mineral deposits. Other sources of power might be practically unavailable in these areas and piles might make it possible, therefore, to gain added mineral resources for mankind. While these mineral resources were being made available for man's use, one or both of the other byproducts might also be produced which could have the result of making the entire operation very economical.

Another possibility is the use of the pile to make desert or semi-arid land highly productive by using the power to provide water for irrigation purposes . . .

contract for army reactor for Arctic use to be let July 15; Eisenhower atomic pool proposal aimed at such things

There is, of course, the possibility of developing power plants for naval vessels and, eventually, for other uses. These questions are already under discussion and need not be elaborated upon here.

Nautilus launched 1/21/54

In connection with the production of end products such as [element] 49, no one can now foresee the ultimate possibilities . . . it would seem wise at this time to err on the

gamma liquid-level gages now sold commercially

determination of the level of a precipitate in a vessel which is closed and opaque. If the precipitate contained tagged atoms the concentration of these atoms in various horizontal planes could be determined with Geiger counters. Another possibility is the automatic control of various processes based on the Geiger count.

$25-million estimated business in '54

The field of instruments relating to nucleonics will be very large. The need for instruments in this field is, perhaps, greater than that of any other so far uncovered . . .

There will also be required a most intensive study of shields. The most economic shield will be required for some uses, the lightest shield will be required for others, and the shield occupying the least volume will be required in still other applications. The shield problem will have to be broken down into the alpha, beta and gamma radiation efficiencies as well as for neutrons. Not only will shielding materials have to be intensively studied, but shields will have to be engineered as well.

Types now planned:
① low-flux & high-flux research reactors
② low-power package reactors
③ high-power central station plants

. . . In the future there will be need for large piles and small piles, for low-temperature piles and for high-temperature piles, for high-output piles and for low-output piles. There will be need for the dissipation of a maximum amount of energy in minimum space . . . Consumption of the chain-reacting material may vary all the way from a

* These numbers were wartime designations for Pu^{239} (49), U^{235} (25), and U^{233} (23).

optimistic side of the possibilities of such end products. If the military value is great, then it may not be possible to put a money value on the production of end product . . .

The end products would also be expected to have their peacetime applications. Some of these applications would be in connection with piles, and other applications may develop. For example, it may be possible at some time in the longer future to establish the lines of stress relief in the earth's crust at locations comfortably removed from those of high density of population. The break of the West Coast, which is the seat of stress relief for a large area of the earth's crust in that region, might be moved out into the desert country by the utilization of tremendous detonations . . .

tremendous demand impending for Pu 239, U 233 and U 235 as nuclear fuels and for D_2O as reactor moderator

Now, in connection with nucleonics, it may be that heavy water, 49, 23 and 25, and possibly other materials, will be rated as national assets much as gold has been in the past . . . Any one of these end products would be so scarce that there would seem to be no danger of overproduction for generations. I do not know to what extent heavy water might become a national asset in the future, but it is possible that its status will be determined in no small measure by the status of the pile and the value of the end products.

Beryllium important as reactor moderator

It seems now that beryllium has unique properties in nucleonics. It may be found desirable to establish a large stockpile of this metal as a national asset . . .

The experimental scientists have much to do in gaining new facts for the theoretical scientists to work with. In due course there should be as good an understanding of the structures of atomic nuclei as now obtains in connection with electron arrangements. When this day arrives, who knows what sweeping predictions may be made to guide experimenters straight to goals otherwise attainable only by cut-and-try methods? . . .

legislation now before Congress to do just this

The nations putting in the most effort in nucleonics after the war may be expected to reach this objective ahead of the lagging nations. The nations which establish conditions favorable to extensive research in nucleonics may be expected to show a greater advance in the science and art than nations which, intentionally or otherwise, have policies or laws which discourage research and development in this field . . .

. . . If the United States unduly restricts scientific and industrial activities in nucleonics, and other countries do not, such other countries should eventually have a military advantage over us. It is, therefore, of vital importance to the future of the United States that proper relationships be established between governmental and nongovernmental agencies.

The broad objectives, in my opinion, should be:

1. To stimulate widespread research in nucleonics in the United States.

2. To encourage the development of the nucleonics industry in the United States.

3. To harmonize the military and other governmental activities in nucleonics in such a way as to insure maximum national security.

While the procedures necessary for the accomplishment of these objectives may not now be obvious, and while they may be expected to be changed from time to time as experience is gained, I believe these objectives can be substantially achieved. Some suggestions are offered for consideration:

these have been, will continue to be gov't activities

a. The projects relating to [elements] 49 and 25 should be prosecuted by the government, no matter when the war ends, to a point sufficient for military appraisal.

Congress considering this

b. The development of the nucleonics industry by private enterprise should be encouraged. The military byproducts of the industrial developments should be made available to the government, and the use of government information and patents should be made available to industry so far as the military situation may permit.

this is AEC

c. A suitable agency, with both government and nongovernment representatives, should be established to guide and coordinate such nucleonics activities as may affect the military or other interests of the government.

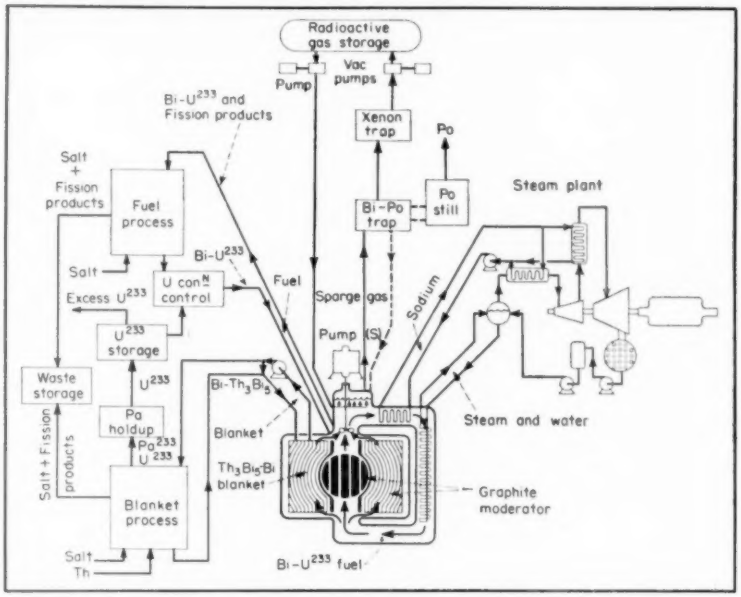
purchase of fissionable materials may not be possible for several years, but controlled leasing may get under way soon

It will be possible to have rather free private enterprise activity and still have the government hold a tight rein on important factors in the nucleonics field. Control of end products need not be so far different from that of gold, except for safety measures. No one may hoard gold, yet the gold industry is quite free. Gold production is in private hands and anyone may purchase it for use in the industries and arts . . .

Researchers normally have little difficulty in getting gold or ethyl alcohol for experimental purposes. Similar arrangements could be made if the government had control of all end products. The same might be true of certain of the raw materials involved . . . The military need could always be given first preference.

Such an arrangement would contemplate continual governmental research and would encourage private research. The researches of these two groups should not be regarded as competitive, but as complementary, and even cooperative so far as this is possible. Private enterprise should be given an incentive to do work in nucleonics: otherwise, the development may lag here in comparison with that in other countries where incentives obtain . . .

LMFR power reactor systems . . . give these advantages:



CORE, HEAT EXCHANGER, STEAM POWER GENERATOR, PROCESSING SYSTEMS are shown schematically for an LMFR. Core is a graphite moderator structure with liquid-metal fuel flowing through it. Fuel is solution of fissionable U^{233} in molten bismuth. Shape and size (about 5 ft in diameter) allow chain reaction to occur. Fission energy raises fuel temperature. Fuel, pumped through heat exchangers, transfers its heat to liquid sodium, then boiling water; cooled fuel is pumped back into bottom of core. Steam flows to turbogenerator; sodium provides superheat, reheat. Thermal efficiency is over 35%. Integral processing systems: pass sparge gas through fuel to remove gaseous fission products and Po; remove solid fission products from fuel with fused salts; remove fissionable material bred in thorium-containing blanket

- **High specific power**
- **High-temperature operation and thus high thermodynamic efficiency, but without high pressures in the reactor**
- **Good enough neutron economy to give some breeding with resulting low fuel costs**
- **Relatively simple construction**
- **Easy fuel handling by pumping**
- **Cheap chemical processing to remove fission products, integrated into reactor design**
- **Lack of radiation damage to liquid-metal fuel**
- **Unlimited burn-up of fuel (two preceding items)**
- **Removal of relatively fresh fission products in concentrated form. This may allow reduction of exclusion area. Fission products may be useful by-products, are at worst easily stored wastes**

Liquid Metal Fuel Reactor Systems for Power

By C. WILLIAMS and F. T. MILES

Nuclear Engineering Department, Brookhaven National Laboratory, Upton, New York

NUCLEONICS *is publishing this series of seven articles on LMFR not only because of its technical value, but because it is the most comprehensive study of power reactor design factors available to date.*

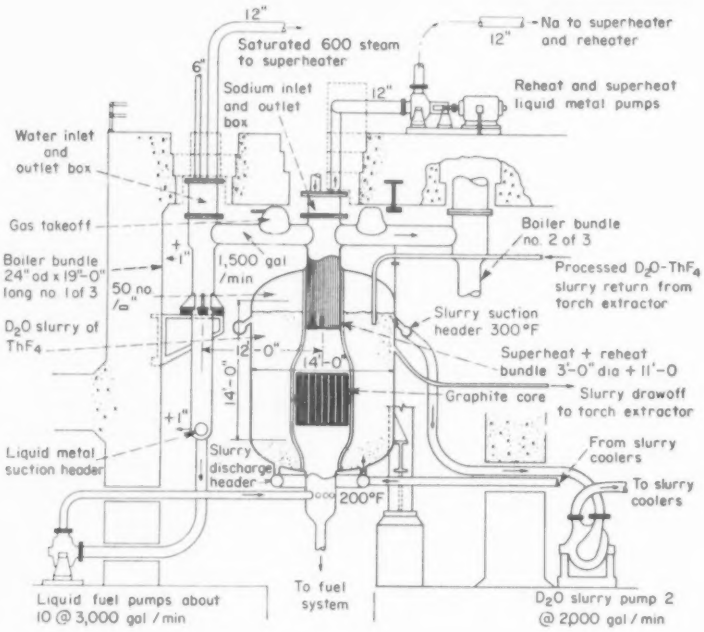
—The Editors

A FEW YEARS AGO the Brookhaven Nuclear Engineering Department started a search for reactor components that would give the greatest ultimate promise for development of cheap electric power from fission heat. A reactor that would use a liquid-metal solution or dispersion of U^{233} as fuel and that would breed the U^{233} from thorium appeared to have many desirable features. Such a liquid-metal-fuel reactor, or LMFR, might have such low capital costs per kilowatt and such low operating costs that the electric power would be produced at a price competitive with conventional fuels.

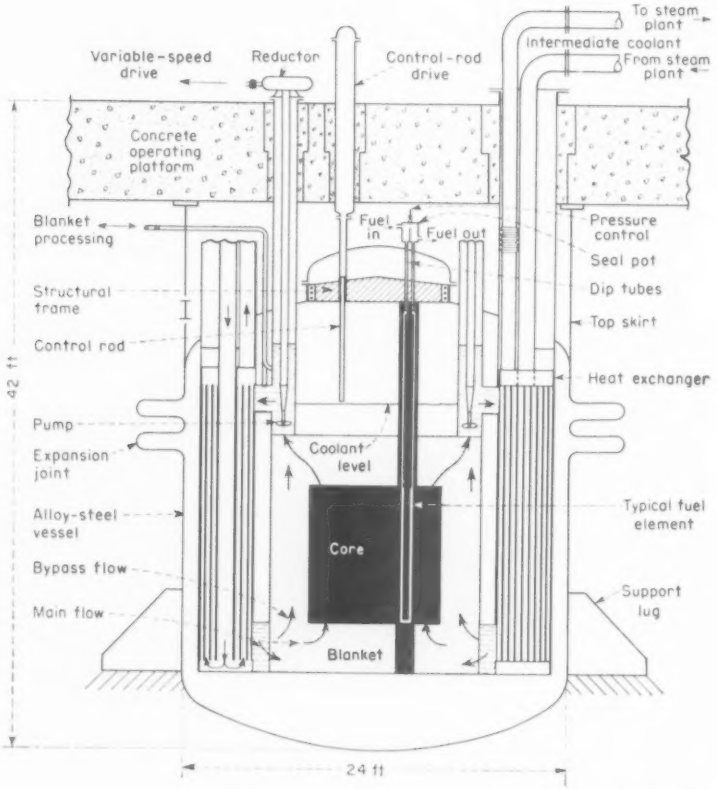
Because the LMFR concept includes unconventional materials and processes on which engineering experience is lacking, a number of problems must be

TWO POSSIBLE LMFR POWER SYSTEMS

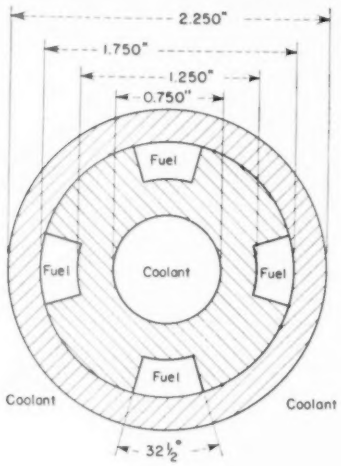
These drawings illustrate two of many possible design concepts for LMFR power reactors operating in the range of 500 Mw heat or 150 Mw electricity

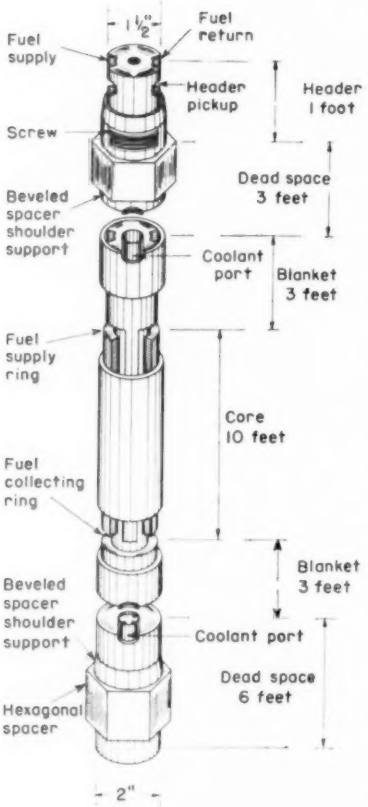


1 EXTERNAL COOLING of fuel outside core provides heat power to drive turbogenerator. Breeding blanket shown is not Th_3Bi_2 slurry but alternate slurry of thorium fluoride in heavy water, cooled by own external heat exchanger



2 FUEL STAYS INSIDE reactor in this design, cutting down fissionable-material inventory. Sufficient fuel concentration is achieved with dispersion of an intermetallic compound of uranium and tin, U-Sn_3, in liquid lead-bismuth-tin. Fuel dispersion is held in annulus of graphite double-walled tube (only one shown) dipping into core and surrounded by coolant. Liquid Bi containing dispersed Th_3Bi_2 functions both as core coolant and as blanket. Breeding occurs in both places. Fertile coolant is circulated to external heat exchanger. Desirable mechanical feature is that all materials are held in single steel pot filled with graphite structure channeled to take coolant, fuel, components such as pump impellers and heat exchangers





3 DOUBLE-WALLED FUEL TUBE can hold fuel in core as in 2, or thorium-carrying dispersion in blanket. If latter, U-Bi solution fuel is circulated to external heat exchangers, cools both core and tubes in blanket

solved before the first large pilot reactor can be designed. Then pilot operating experience will be needed to choose the most economical plant design.

This article summarizes the present status of LMFR, listing the problems already solved and those to be solved. Details are given in the following six articles.

Fuel Selection

The first problem is selection of a suitable fuel. Solutions of uranium in bismuth were suggested by Halban and Kowarski as far back as 1941. Bismuth has a suitably low cross section, and liquid metals in general are expected to be completely free from radiation damage. Solubility has been measured (see p. 14) as about ½% U in Bi at 500° C. This is more than ample for a chain reaction in an enriched-fuel reactor; LMFR fuels considered here consist of 600–1,000 ppm U in Bi, a dilution that gives high specific power and contributes to reactor efficiency.

Container Materials

Graphite appears to be satisfactory in contact with Bi-U so that the moderator in the core need not be clad. But a metal is needed for heat-exchanger tubes and probably for the outer container. Mass transfer is the problem, as it was in development of the mercury boiler and turbine. A similar solution, use of inhibitors, has proved satisfactory with bismuth.

Corrosion experiments described in the articles on pages 20 and 40 give confidence that U-Bi solutions with inhibitors can be circulated in commercially available alloys. Possible containers for operation above 600° C are being studied.

Chemical Processing

The most important feature of LMFR is integration of chemical processing with the reactor. In the long run, maximum operating economy is thus achieved. Several different processes act on the U-Bi fuel.

First, after each passage through the core—about every 15 sec—the fuel stream is sparged with an inert gas that removes gaseous fission products, especially I or Xe^{135}. The gases are pumped through a trap, which might well serve as a gamma-ray source, to a storage tank, then back into the fuel.

Some bismuth probably will distill off in this gas, carrying polonium formed by neutron capture with it. Although separated Po is an undesirable material, Po dissolved in Bi poses no greater hazard than the fission products. The distilled Bi and Po could be remelted and returned to the fuel. If desired, byproduct Po could be separated by fractional distillation; its value should pay for any additional precautions it demands.

A more important fuel processing cycle is extraction of rare-earth fission-products from the liquid-metal fuel, by contacting it with a fused salt. Uranium is left in the Bi solution.

Research has proceeded along two main lines. First, the thermodynamics have been used to explain the theory of the process. This approach, and the experiments performed to check critical points, is described on page 16. Second, circulating loops in which fuels are contacted with fused salts have been built to obtain engineering data. Details are given on page 20.

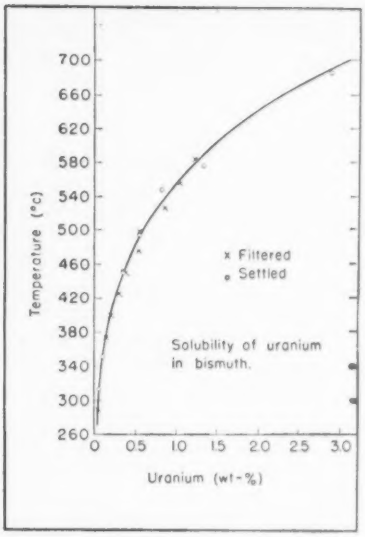
Some difficulties have been encountered; they do not appear unsurmountable.

Breeder Blanket

Nuclear power fuel costs will be low only if natural uranium or thorium rather than previously separated U^{235}, U^{233}, or plutonium, is used. In other words, the fuel must be replenished by breeding. In LMFR this is done in a breeder blanket that surrounds the core and captures excess neutrons leaking out from the chain reaction in the core. The blanket consists of graphite moderator pierced by tubes holding fertile thorium, as thorium bismuthide (Th_3Bi_5), dispersed in liquid bismuth. Some heat will be produced in the blanket; this is removed by circulating to an external heat exchanger or, as shown on p. 12, by bypassing some fuel through the blanket. Details of the blanket are discussed in the articles on pages 14, 16, and 26.

In one proposed process, the blanket material would be pumped to a processing plant, and diluted with enough Bi at high temperature so that all Th_3Bi_5 would go completely into solution. Pa and U formed by neutron capture would be removed by a modified fused-salt extraction; U would be separated in a hold-up tank and then stored for fuel makeup or sale.

An alternate blanket system using thorium fluoride is described on page 26.



U-Bi solution and . . .

Solid		Liquid		Freezing point (° C)
Compound	Density (gm/cm³)	Compound (wt %)	Density (gm/cm³)	
U_3Bi_5	12.4	Bi	10.0	273
U_3Bi_5	12.4	55.5 Bi, 45.5 Pb	10.3	125
UBi	12.5	85 Pb, 15 Bi	10.5	300
USn_3	10	5 Sn, 35 Bi, 60 Pb	10	160
USn_3	10	6 Sn, 56.2 Bi, 37.8 Pb	9.8	115
Th_3Bi_5	10.5	Bi	10.0	273
Th_3Bi_5	10.5	55.5 Bi, 44.5 Pb	10.3	125

Intermetallic compound dispersions in U-Th-Pb-Bi-Sn systems can be used for . . .

. . . Liquid-Metal Fuels and Breeder Blankets

By R. J. TEITEL, D. H. GURINSKY, and J. S. BRYNER
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Upton, New York

LIQUID-METAL REACTOR fuel and breeding systems having reasonable melting points can be obtained by adding low-melting-point diluents to high-melting thorium and uranium. Neutron cross section is the primary consideration in choosing diluents.

Because bismuth, lead, and tin have both low melting points and low cross sections, alloys and dispersions of these metals were investigated as possible LMFR fuel and breeder materials. Three liquid-metal systems were studied: solutions of Th and U in liquid metals; intermetallic compounds of Th and U suspended in liquid lead-bismuth-tin alloys; and ionic compounds such as oxides, nitrides, etc., suspended in molten alloys.

A rough survey of the densities and wettabilities of ionic compounds indicated that they held little promise of stable dispersions. Consequently, little effort was expended beyond the survey.

Phase diagrams of U-Th-Pb-Bi-Sn alloys have been studied for the past five years. This article summarizes the results.

Single-Phase Solutions

The only satisfactory single-phase fuel uncovered is the solution of U in Bi. Solubility of U in Bi is plotted as a function of temperature on this page. Even though the solubility is not large, nuclear calculations show that a prop-

erly designed reactor can utilize this solution as fuel. Solubility limits need not be exceeded to obtain a feasible temperature cycle at concentrations of 600–1,000 parts per million.

In general, the solution's properties are similar to those of bismuth. However, the chemical activity of uranium requires extra precautions to prevent loss of uranium through oxidation or other reactions.

U-Pb-Bi-Sn Dispersions

Intermetallic compound dispersions are formed when solubility limits of U or Th are exceeded in Bi-Pb-Sn alloys. Some possible liquid-metal dispersions found from phase diagrams of these systems are compiled in the table on this page. Properties pertinent to reactor application are also listed.

The compound U_3Bi_5 can be dispersed in Bi or Pb-Bi alloys containing up to 80% Pb. This intermetallic compound is pyrophoric when exposed to air, making it difficult to determine its density by direct experiment. The value given is based on its crystal structure as determined by neutron diffraction. Density is greater for the solid than for the liquid, and some settling should occur in dilute dispersions.

Addition of lead decreases the solubility of uranium. For example, at 400° C, 0.20% U is soluble in Bi, while only 0.013% dissolves in the Pb-Bi eutectic.

The table indicates that a wide selection of freezing points is possible. This system might be considered either for a fuel or for a plutonium breeder system.

Another intermetallic compound, UBi, is in equilibrium with Bi-Pb alloys containing 80–98% Pb below 600° C. Like U_3Bi_5, it is pyrophoric. Its density was also obtained from its crystal structure. This dispersion may be useful where applications require higher concentrations of uranium than those available in the U_3Bi_5 dispersion.

The intermetallic compound USn_3 is apparently stable in many Bi-Pb-Sn alloys. Its density is close to that of lead and bismuth-rich low-melting alloys. Not as pyrophoric as the other metallic compounds, its density and structure are well known. The unit cell contains uranium atoms on the corners of a cubic lattice with tin occupying the cube's faces. Hardness approximates that of pure iron.

Choice of dispersions in this alloy system depends upon reactor design requirements. The density of USn_3 is matched by liquid metals containing 3–5% Sn, 35–40% Bi, and the remainder Pb. Freezing points down to 95° C are attainable in compositions around the ternary eutectic composition. The examples in the table illustrate these extremes.

Nuclear considerations favor the lower tin content; the capture cross section of tin is higher than that of bismuth or lead. Furthermore, because of the high capture cross section of tin, consideration of these dispersions for breeders producing plutonium is doubtful.

Use of USn_3 as a fuel has been proposed in a reactor design where the fuel is held stationary and a separate coolant removes fission heat. This application requires higher uranium concentrations than those attained in solution-type fuel.

Th-Bi-Pb Dispersions

Another group of intermetallic compound dispersions were found in the Th-Bi and the Th-Bi-Pb systems. These systems are not known completely, but it has been definitely established that a compound having 40% Th (probably Th_3Bi_5) is in equilibrium with most of the Bi and Bi-Pb alloys. This compound's density does not differ greatly from those of Bi and Pb-Bi alloys. Freezing points range from 273° to 125° C.

These dispersions have been proposed for use in two reactor designs. One calls for a thorium dispersion that is used both as a coolant and as a mobile blanket; the other uses the dispersion in a stationary external blanket (see p. 12).

Maximum Concentrations

Viscosity limitations determine the maximum concentration of U or Th in these dispersions. It is generally assumed that dispersions containing below about 25% solids by volume move easily. Above this concentration, viscosity rises sharply. This knee in viscosity vs volume per cent solids shifts somewhat depending on particle size, shape, and distribution. On the basis of the 25% limitation, about 10% Th or U is the maximum concentration for systems in which the compounds Th_3Bi_5 or U_3Bi_5 are used.

Four Ways to Prepare Intermetallic Compound Dispersions

The dispersions discussed in this article can be prepared on a laboratory scale by four methods:

1 DIRECT PREPARATION. All of these dispersions can be made by heating the constituents in a graphite crucible to 1,200° C for an hour and then cooling. Particle size and shape depend on alloy composition and mode of precipitation. The compounds U_3Bi_5 and Th_3Bi_5 precipitate from solution as platelets; the compounds USn_3 and UBi, as equiaxed particles. In general, the higher the concentration the greater the platelet thicknesses and the larger the equiaxed-particle diameters.

2 EXFOLIATION. If chips of Th or U are added to the molten low-melting alloy at a low temperature, they react and the product exfoliates away. Size and shape of particles produced depend on reaction temperature. For example, when Th chips react with Bi at 500° C, particles are equiaxed and have diameters of about 30–40 microns. At higher temperatures, particle size would be larger.

3 HYDRIDE DECOMPOSITION. Another method for controlling size and shape of particles is to add finely powdered U or Th to the liquid-metal bath under a protective atmosphere at low temperature. Powdered U or Th can be produced from the hydride. Technique is to form hydride that exfoliates away from the solid or forms a brittle mass that can be crushed into a fine powder. Hydride is then decomposed at low temperature, leaving finely divided U or Th. This method is particularly suitable for U. Particle size of U prepared from hydride is about 1 micron; that of intermetallic compound, about 3 microns. If uranium hydride is added directly to molten metal, compound is so finely divided that it is beyond microscopic resolution.

4 ELECTROLYSIS. A fused salt containing U or Th is electrolyzed into a molten-alloy cathode. This method is being studied; finely divided dispersions should be producible.

LMFR PART III

Fused Salts for Removing Fission Products from U-Bi Fuels

Experiments indicate feasibility of extracting fission products from LMFR's uranium-bismuth fuel solution by treating it with a fused salt. Theories involving known properties of rare-earth compounds substantiate experiment

By D. W. BAREIS,* R. H. WISWALL, Jr., and W. E. WINSCHE†
Nuclear Engineering Department, Brookhaven National Laboratory, Upton, N. Y.

BROOKHAVEN's "LMFR" reactor design calls for extraction of fission products from a solution of uranium in bismuth by treatment with a fused salt. This article describes experiments that substantiate the feasibility of such an extraction process and interprets results in terms of known properties of compounds involved.

Rare-earth metals dissolved in liquid bismuth can be extracted nearly quantitatively by equilibrating the bismuth with a fused KCl-LiCl mixture at 450° C, while uranium in such a system remains in the metal phase. Values of distribution coefficients, and how they are affected by changes in salt- and metal-phase compositions, and other variables are discussed.

Fair quantitative agreement between theory and experiment is demonstrated by interpreting the data as being based on the hypothesis that a process of chemical reaction (rather than solvent extraction) is involved. Partition of various elements between salt and metal is explained mainly in terms of stability of their halides.

Background. Early studies indicated that liquid-liquid extraction would be an advantageous method for fuel processing. A fused salt seemed the most likely extracting liquid; it and bismuth have almost zero mutual solubility, and salts were available that had convenient melting points and were stable at high temperatures. Salts meeting these conditions were tested for reactivity toward uranium-bismuth alloy at 450° C.

Chlorides of lithium, potassium, calcium, barium and magnesium, used in various low-melting mixtures, were entirely inert, while chlorides of cadmium, zinc and beryllium reacted, as shown by transfer of uranium into the salt phase. A third class of salts was found to react even with pure bismuth; these included cupric chloride and silver chloride.

A few experiments were done on bismuth solutions of uranium that had been irradiated with thermal neutrons. When these alloys were equilibrated with salt mixtures such as LiCl-KCl or LiCl-KCl-$BaCl_2$, which had been shown not to affect uranium, a significant decontamination was effected. This led to a series of more closely controlled distribution experiments on single elements instead of fission-product mixtures. From these experiments a self-consistent body of data was obtained that points the way to a practical decontamination process.

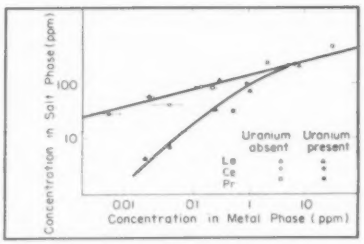


FIG. 1. Distribution of rare earths between liquid bismuth and fused salt mix

PROCEDURES AND RESULTS

The elements used were the rare earths lanthanum, cerium, and praseodymium obtained from the Ames Laboratory in metallic form, activated in the Brookhaven reactor to permit use of radioactivity in the analyses. Dilute solutions of these metals in bismuth were equilibrated at 450° C with the fused eutectic mixture of KCl and LiCl. A few hours contact sufficed to reach equilibrium. After cooling, the solidified phases were separated for analysis.

Two series of experiments were carried out—to determine the distribution of rare-earth solutes alone, and in the

Various Salts' Free Energy of Formation at 500° K*

Salt	$-\Delta F$ (10³cal/ gm-atom of Cl)	Salt	$-\Delta F$
CsCl	94.6	$BeCl_2$	48.3
RbCl	93.9	$AlCl_3$	48.1
KCl	93.1	$MnCl_2$	47.6
$BaCl_2$	92.8	$ZnCl_2$	40.6
$SrCl_2$	89.0	TlCl	40.5
LiCl	88.8	$CdCl_2$	38.0
NaCl	87.4	$CrCl_3$	34.7
$CaCl_2$	86.4	$GaCl_3$	34.3
$LaCl_3$	76.0	$InCl_3$	33.8
YCl_3	69.5	$PbCl_2$	33.9
$PuCl_3$	67.4	$FeCl_2$	33.2
$MgCl_2$	66.8	$SnCl_2$	32.6
$ScCl_3$	64.3	$NiCl_2$	27.8
UCl_3	62.2	CuCl	25.7
$ThCl_4$	61.8	AgCl	23.5
UCl_4	53.9	$BiCl_3$	22.2

* Values for uranium compounds from ref. (6); for plutonium compounds, from ref. (7); for all others, refs. (1) and (8).

* PRESENT ADDRESS: North American Aviation, Inc., Downey, California.

† PRESENT ADDRESS: E. I. DuPont de Nemours, Inc., Wilmington, Delaware.

presence of uranium. Three different elements were used in each series—lanthanum, cerium and praseodymium—and the concentration of each was varied over a wide range. In no case did the equilibrium concentrations of solute species in salt and metal phases exhibit a constant ratio. However, a certain regularity was apparent (Fig. 1).

With uranium absent, the straight line conforms to lanthanum data; it also represents cerium and praseodymium points pretty well, as might be expected from the chemical similarity among these elements. The line's slope is just $^1/_4$; that is

$$\frac{(\text{conc. in salt})^4}{(\text{conc. in metal})} = \text{constant} \quad (1)$$

In systems containing both uranium and a rare earth, the distributions were quite different. The lower set of points in Fig. 1, through which the curved line is drawn, present the data. Uranium in these experiments distributed itself like rare earth, between salt and metal phases; but where rare earth favored the salt phase, uranium remained preponderantly in bismuth. The quantity of importance is the separation factor

$$\frac{\text{rare earth in salt/rare earth in metal}}{\text{uranium in salt/uranium in metal}}$$

Values of this quantity yielded by experiments that gave rare-earth distributions plotted in Fig. 1 were of the order of 10^4.

The distribution of a few elements other than rare earths was determined under similar conditions. Semiquantitative results obtained showed that lead, tin, and polonium remained almost entirely in the metal phase. Plutonium was found in both, but favored the metal; barium and neodymium went mostly into the salt. Addition of sodium metal to the system made the metal phase retain both uranium and rare earths quantitatively.

Fourth-Power Relation

It is well known that a fused salt can act as a solvent for metals. Solubility may be quite large for a metal dissolving in its own fused halide. Smaller though significant, solubilities have been measured in systems of a salt equilibrated with a foreign metal.

The solubility of cadmium in manganous chloride is an example (*2*). If in such systems metal were present, not in the pure state but as a dilute solution in another metal such as bismuth, it should distribute itself between metal and salt phases according to Nernst's distribution law. To a first approximation, the ratio of concentrations should be independent of concentration. Clearly this is not so for distributions shown in Fig. 1.

The relation could be explained in terms of Nernst's law only by postulating that the solute undergoes association in one of the phases; i.e., in this case, that a tetramer forms in the metal phase. A more likely explanation is that we have an example of that class of reactions known as "slagging."

In the typical slagging operation, a molten salt or oxide mixture reacts with and extracts undesirable constituents of a metal melt. If, for example, chromium and manganese are to be removed from molten iron, a slag containing iron oxide is used; an exchange of oxygen occurs, and the chromium and manganese oxides go into the slag.

In a similar way, bismuth is purified of all base-metal impurities by a selective chlorination.

At first glance, no such mechanism would seem possible in transfer of rare earths from bismuth to fused LiCl-KCl eutectic. The free energy of formation of these salts is very much more negative than that of any rare-earth chloride, so the equilibrium position of any such reaction as

$$3\,\text{LiCl} + \text{La} \rightleftharpoons 3\,\text{Li} + \text{LaCl}_3 \quad (2)$$

is far to the left. A numerical calculation, however, shows that traces of rare-earth metal can be oxidized nearly completely by pure LiCl (due to the mass-action effect).

Given concentrations used in these experiments, the results are not inconsistent with such a chlorination mechanism. Furthermore, dependence of distribution ratio on concentration is just what the analysis predicts. Equilibrium constant for Eq. 2's reaction is

$$K_2 = [\text{LaCl}_3][\text{Li}]^3/[\text{La}][\text{LiCl}]^3 \quad (3)$$

where bracketed quantities are equilibrium thermodynamic activities in the system. They are the same, for each species, in both salt and metal phases, if the pure substance is taken as the standard state for each.

Since the system was formed by mixing pure LiCl and La, components on the right side of Eq. 2 must be present in stoichiometric proportion

$$N_{\text{Li}} = 3\,N_{\text{LaCl}_3} \quad (4)$$

where N is total moles of a species.

Let it be assumed that each salt component of the system is insoluble in the metal phase but forms an ideal solution in the salt phase, while each metallic component is insoluble in salt but forms an ideal solution in the metal phase. Then activity of a component is equal to its mole fraction in the phase in which it is soluble; for example

$$[\text{Li}] = X_{M,\text{Li}}$$

where term on right denotes mole fraction of lithium in metal phase and is

$$X_{M,\text{Li}} = N_{\text{Li}}/N_M$$

where N_M is total number of moles of metal in the system. Similar relations apply to the other components. Making use of them and of Eqs. 3 and 4, we may write the equilibrium constant as

$$K_2 = 27\,\frac{N_S{}^3}{N_M{}^3}\,\frac{X^4_{S,\text{LaCl}_3}}{X_{M,\text{La}}X^3_{S,\text{LiCl}}} \quad (5)$$

Since lithium chloride is present in great excess over other reactants, its mole fraction, $X_{S,\text{LiCl}}$, is practically constant. Total quantities of salt and metal, N_S and N_M, are also constant, so that this equation predicts a fourth-power relationship between the quantities of lanthanum present in the combined form and as the element. This relationship is just what was found in experiments and is shown by Eq. 1.

Slagging Hypothesis

We must now consider to what extent the form of Eq. 5 depends on the approximations used, and whether they are plausible.

Assumption of negligible mutual solubility of metals and salts is essential. If much of any element in the salt phase had arrived there by simple solution, this fraction would bear a constant ratio to the concentration in the metal phase and the fourth-power relation would be disrupted to that extent.

Generally, even pure metals dissolve but little in salts, and it is unlikely that any salt would extract a dilute component from an alloy. Salts are even less soluble in metals, so there is little doubt that rare earths and uranium (when in the metallic state) will be found almost entirely in the bismuth phase, and when combined as halides, in the salt phase.

The derivation of Eq. 4 assumed that no side reactions occur. Thus, the equation is valid only if the bismuth in which rare-earth metals are dissolved acts as a completely inert solvent. Extent of the reaction

Other Applications of Liquid Salt-Metal Systems

Liquid salt-metal systems should be useful in nuclear engineering processes other than fission-product removal. The selectivity of the chlorination is such that two chemically-similar elements can be cleanly separated if the free energies of formation of their halides differ by even a few kilocalories.

Under the assumptions made in connection with this article, the separation factor is numerically equal to the equilibrium constant of the reaction

$$A + BCl \rightleftarrows ACl + B$$

and is, therefore, given by the expression $\exp(-\Delta F/RT)$. Figure 2 presents values of this function at three different temperatures. It is clear from this graph that, in most cases, a good separation will be obtainable from a single stage. If counter-current contacting equipment can be devised for such systems, almost any pair of elements should be separable.

A continuously-processed breeder blanket would be a promising field in which to apply this principle. A blanket in which the bred material is continuously separated from the fertile matrix has much to recommend it.

It should not be hard to separate either plutonium or thorium in an appropriate salt-metal system. Work is in progress at Brookhaven on blanket formulations that lend themselves to this kind of treatment.

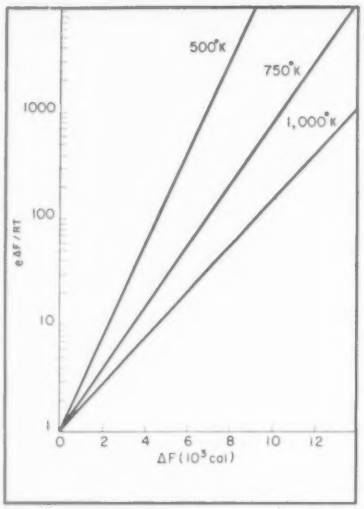


FIG. 2. Equilibrium constant at 500, 750, and 1,000° K

$$Bi + 3\,LiCl \rightarrow BiCl_3 + 3\,Li \quad (6)$$

must be orders of magnitude smaller than the corresponding reaction for any solute element.

Inspection of the free energies of formation of the two chlorides concerned shows this to be the case. The table presents values of this function for these and other chlorides of interest to BNL's program. Value tabulated for each is the free energy per chlorine atom; it is this figure that is a direct index of the salt's stability. From the numbers given it can be seen that the free energy of Eq. 6's reaction at 500° K is $+ 2 \times 10^5$ cal. That of Eq. 2's reaction, however, is $+ 3 \times 10^4$ cal. The corresponding equilibrium constants, as given by

$$\Delta F = -RT \ln K \quad (7)$$

are 3×10^{-55} and 8×10^{-14}.

It is evident that bismuth is indeed inert as far as this type reaction is concerned. Thus the assumptions are reasonable, the agreement of Eqs. 1 and 5 is meaningful, and it is worthwhile to compare quantitatively theory and experiment.

Theory vs. Experiment

A rigorous equation can be derived to show the distribution behavior in cases where both chemical and physical modes of transfer are significant. This equation

$$K_2 = \frac{AB^3}{CD^3}\frac{1}{N^3_{LiCl}}\left[\frac{1}{1+\dfrac{[KCl]}{K_{19}[LiCl]}}\right]\times \frac{X^4_{S\text{-}LaCl_3}}{X_{M\text{-}La}}\frac{\left(N_S + N_M\dfrac{X_{M\text{-}LaCl_3}}{X_{S\text{-}LaCl_3}}\right)^4}{\left(N_M + N_S\dfrac{X_{S\text{-}La}}{X_{M\text{-}La}}\right)} \quad (8)$$

is a useful point of departure for comparison of theory and experiment. In Eq. 8, A, B, C, and D are functions of activity coefficients; K_{19} is an equilibrium constant; and the term in brackets is an adjustment for the presence of KCl as well as LiCl. Since KCl is more stable than LiCl by only 4.3×10^3 cal, an exact calculation must take account of the chlorinating potentials of both.

Many of the quantities in Eq. 8 must be estimated roughly. Thus, close agreement cannot be expected, but an order of magnitude calculation is worthwhile.

The equation's term most sensitive to data error is the equilibrium constant, K_2. This is evaluated by Eq. 7, where ΔF is, in this case, that of Eq. 2. An error of one kilocalorie in this ΔF (which is itself a difference between two larger experimental quantities) changes K by a factor of two at 723°, the temperature of the distribution experiments. In view of the admitted uncertainties in standard tables of free energies, an error of several kilocalories is not unlikely. Therefore, it is legitimate, in solving Eq. 8, to admit approximations that will produce errors much less than the unavoidable large error arising from ΔF's uncertainty.

Such approximations are that:

1. The ratios $X_{M\text{-}LaCl_3}/X_{S\text{-}LaCl_3}$ and $X_{S\text{-}La}/X_{M\text{-}La}$ are practically zero.

2. Assumption 1 is equivalent to saying that the activity coefficients $\gamma_{M\text{-}LaCl_3}$ and $\gamma_{S\text{-}La}$ are very large, mole fractions and activity coefficients being inversely proportional here. The same statement can be made for lithium and lithium chloride.

3. N_S and N_M are assumed equal.

Equation 8 now reduces to

$$\frac{X^4_{S\text{-}LaCl_3}}{X_{M\text{-}La}} = \frac{e^{\frac{-\Delta F}{RT}}}{27\dfrac{\gamma_{S\text{-}LaCl_3}\gamma^3_{M\text{-}Li}}{\gamma_{M\text{-}La}\gamma^3_{S\text{-}LiCl}}\dfrac{N^3_S}{N^3_{LiCl}}} \times \frac{1}{1+\dfrac{[KCl]}{K_{19}[LiCl]}} \quad (9)$$

Activity coefficients of salts in salt, $\gamma_{S\text{-}LaCl_3}$ and $\gamma_{S\text{-}LiCl}$ can be taken as unity without introducing a gross error. In those few systems of mixed fused salts whose thermodynamic functions have been obtained, departures from the ideal have been moderate (*3, 4*).

Activity coefficients of metals in bismuth solution, $\gamma_{M\text{-}Li}$ and $\gamma_{M\text{-}La}$, are certainly much less than unity. Bismuth forms high-melting, strongly exothermic intermetallic compounds with many metals, including lithium, potassium, magnesium and cerium. For dilute solutions of magnesium in bismuth, γ_{M_g} is only 0.1, or less (*5*). Sim-

ilarities in phase diagrams make it reasonable to assign this value to the γ's.

The value of N_S/N_{LiCl} is 1.695, since the salt mixture was 59 mole % LiCl. This datum also supplies numbers for [KCl] and [LiCl], if the γ's are taken as unity. K_{19} can be calculated, like K_2, from tabulated free energies of formation of chlorides; its value is 7.0 at 723° K. The most crucial quantity, as discussed above, is ΔF in Eq. 2. The best figure available is 3.9×10^4 cal (probable error of $2\text{–}3 \times 10^3$ cal).

A numerical value for the right-hand side of Eq. 9 can now be calculated. The left-hand side can be considered identical with the left-hand side of Eq. 1. This is justified by the fourth-power dependence of the experimental results. After applying a conversion factor in going from the ratio expressed in mole fractions to that expressed in parts per million (Fig. 1), the result is

$$\frac{(\text{ppm, La in salt})^4}{(\text{ppm, La in bismuth})} = 7.8 \times 10^7$$

The experimentally observed value of this constant is 3.9×10^8. If this discrepancy were due solely to an error in the ΔF of Eq. 2, this would be off by 2.3×10^3 cal. In view of approximations made and admitted inaccuracies in published tables, it is fair to say that experiments do not conflict with theory.

Another quantitative test of theory is to calculate ratios of constants for two different solutes. This ratio is free of errors introduced by certain of the assumptions made about the solvent salt, owing to cancellation of terms. The calculation described for La can be repeated for U, giving

$$\frac{(\text{ppm, U in salt})^4}{(\text{ppm, U in bismuth})} = 2.7 \times 10^{-4}$$

This differs from the lanthanum figure by about 10^{11}. Experimental value for uranium is not known with precision, owing to difficulty of analysis at very low concentrations; but it is less than 1.2×10^{-2}, so both this and the lanthanum-uranium ratio are in accord with theoretical values.

Qualitative support for the slagging hypothesis is given by the effect of sodium on the distribution of less active solutes. The observation that it causes rare-earth metals as well as uranium to be retained by bismuth is just what would be predicted. Addition of any alkali metal should shift equilibrium of Eq. 2 to the left, according to the relative free energies shown in the table. This table also suggests that the less stable chlorides, such as those of cadmium, zinc and beryllium, should chlorinate uranium and bring it into the salt phase. This was, in fact, the case.

Extraction from Mixtures

When two solute elements are present together, each affects the distribution of the other. If both U and La are added to a LiCl-metal system, two reactions occur

$$\text{La} + 3\ \text{LiCl} \rightleftarrows \text{LaCl}_3 + 3\ \text{Li}$$
$$\text{U} + 3\ \text{LiCl} \rightleftarrows \text{UCl}_3 + 3\ \text{Li}$$

Neither reaction will go as far toward completion as it would have alone.

An exact analysis is difficult, but it can be seen qualitatively that the La equilibrium, for example, will be noticeably affected by addition of U when the amount of Li produced by the U reaction reaches the order of magnitude of that which would be in equilibrium with lanthanum alone. Product of uranium concentration and uranium equilibrium constant is involved; so, in spite of the great difference between lanthanum and uranium equilibrium constants, concentration of lanthanum in the salt can be diminished by a high uranium content in the metal.

As the lanthanum-uranium ratio decreases, so does the concentration in the salt, and the ratio, lanthanum in salt to lanthanum in metal, approaches a constant value. In terms of the log-log plot, the points fall away from the straight line of slope $^1/_4$ and approach a line of unit slope. Experimental confirmation of this is seen in Fig. 1.

Fission-Product Removal

Rare-earth elements were chosen for distribution experiments because rare earths, as a class, account for a large part of the total poisoning due to fission products. However, they are not the only nonvolatile poisons; distributions of several other species are of interest. If stability of halides is the main criterion, it should be possible to get good separation factors between uranium and all elements in columns 1A, 2A, and 3 of the periodic table. This would take care of the great majority of poisons. Those that would not extract, such as Rh^{103} and Cd^{113}, are not abundant enough to require frequent processing anyway. The problem they present cannot be ignored altogether, but it rates a relatively low priority.

The salt system used in tracer experiments will not be suitable for use in reactor engineering. If the selective chlorination hypothesis is correct, then, for every rare-earth atom oxidized to the trichloride, three alkali metal atoms (mostly lithium) are formed. They go into the bismuth phase. Consequently, they would have a serious poisoning effect on a reactor. Analysis has shown about the right amount of Li in the metal.

Another objection to the LiCl-KCl system is that it is very sensitive to small amounts of oxidizing and reducing impurities; a trace of one will oxidize uranium, a trace of the other will prevent the oxidation of the rare earths.

What is required is a reactant of low cross-section, in a system having buffer capacity; that is, one whose oxidation potential is not drastically changed by the oxidation of a reasonable amount of material. To meet this condition the reactant must be present in both its oxidized and reduced forms in quantities large compared with the amount of fission products to be extracted. It follows that the element must be chosen from one of those whose chlorides lie between UCl_3 and the fission-product chlorides on the free-energy scale.

At first, it appeared that magnesium would be suitable, but recent results indicate that it is too strong a reducing agent. If no other buffer can be found, a satisfactory procedure would be to add an oxidant such as $BiCl_3$ in carefully controlled amounts exactly equivalent to the species to be removed.

* * *

The authors have been helped by discussions with many members of Brookhaven's nuclear engineering department, particularly Francis T. Miles. Manson Benedict of MIT also participated in very useful discussions.

Data analyses carried out independently at NAA, MIT, ANL and BNL reached essentially the same conclusions regarding the experiments.

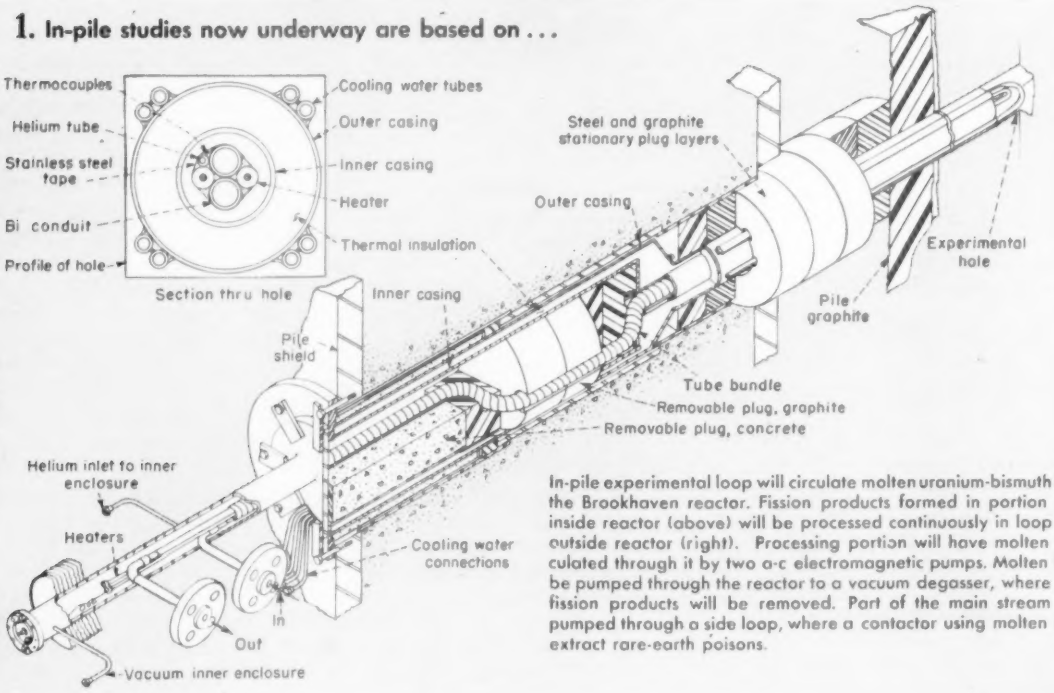
BIBLIOGRAPHY

1. F. H. Spedding, J. P. Flynn, *J. Am. Chem. Soc.* **76,** 1474 (1954)
2. D. Cubicciotti, *J. Am. Chem. Soc.* **74,** 1198 (1952)
3. J. H. Hildebrand, G. C. Ruhle, *J. Am. Chem. Soc.* **49,** 722 (1927)
4. J. H. Hildebrand, E. J. Salstrom, *J. Am. Chem. Soc.* **54,** 4257 (1932)
5. F. H. Vetter, O. Kubaschewski, *Z. Elektrochem.* **57,** 243 (1953)
6. L. Brewer, L. Bromley, P. W. Gilles, N. L. Lofgren, UCRL-BC-82 (1947)
7. G. T. Seaborg, J. J. Katz, W. M. Manning, "The Transuranium Elements," National Nuclear Energy Series IV-14B, p. 861 (McGraw-Hill Book Co., Inc., New York, 1949)
8. L. L. Quill, "The Chemistry and Metallurgy of Miscellaneous Materials: Thermodynamics," NNES IV-19B, p. 76 (McGraw-Hill Book Co, Inc., New York, 1950)

LMFR PART IV

Fuel Processing Loops: How They Are Being Developed

1. In-pile studies now underway are based on ...



In-pile experimental loop will circulate molten uranium-bismuth through the Brookhaven reactor. Fission products formed in portion of loop inside reactor (above) will be processed continuously in loop portion outside reactor (right). Processing portion will have molten fuel circulated through it by two a-c electromagnetic pumps. Molten fuel will be pumped through the reactor to a vacuum degasser, where volatile fission products will be removed. Part of the main stream will be pumped through a side loop, where a contactor using molten salt will extract rare-earth poisons.

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SALT-EXTRACTION of rare-earth fission products has been demonstrated on a laboratory scale (see p. 16). But its feasibility must be proved by an in-pile experiment where operating conditions simulate actual power-reactor characteristics. This article describes tests run to develop components and processing techniques of the in-pile facility shown in Fig. 1.

Several out-of-pile loops (Figs. 2–5) tested construction materials, pumps, valves, instrumentation, and assisted in developing analytical, heating, and sampling methods. Experience with these loops also helped evolve liquid-metal handling techniques.

The apparatus shown in Fig. 1, in addition to being used in material and equipment tests, was also used for fuel-processing experiments.

CORROSION TESTS

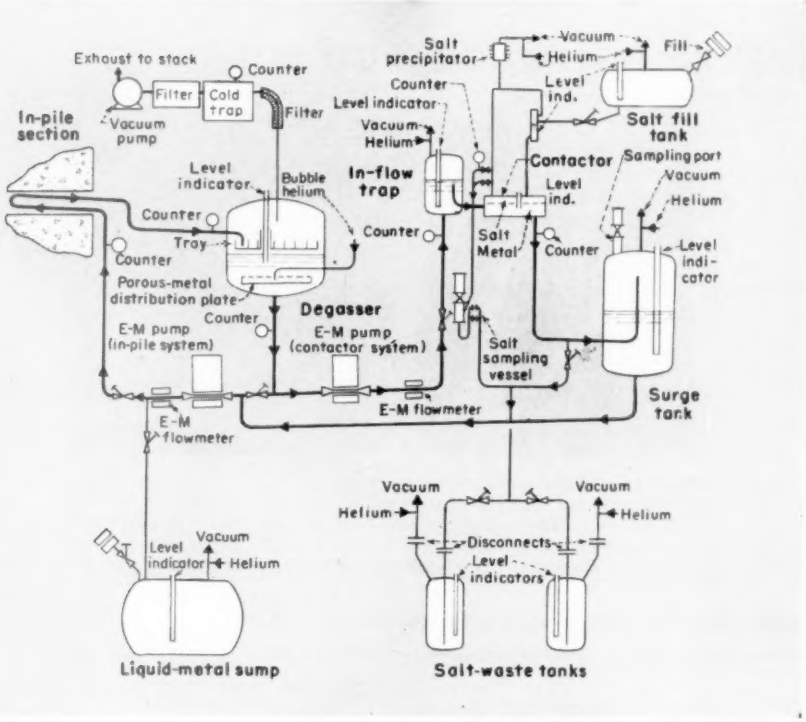
Although there is insufficient metallurgical data to permit choice of a material for eventual use in the LMFR's processing system, dynamic tests described here have led to the choice of type-347 stainless steel for use in the in-pile experimental loop.

Early data. Corrosion tests on a number of commonly-available structural materials (not including austenitic steels) indicate that the intermediate-chromium steels (2 $5\frac{1}{2}$% Cr) show most promise for use at 550° C (*1*). But tests with thermal-convection loops show that these steels have fairly high penetration rates, and plugging occurs unless inhibitors are added to the bismuth (*2*). Corrosion seemed to be excessive in a few static corrosion tests run with intermediate-chromium steels in contact with LiCl-KCl eutectic at 500° C.

Early static corrosion tests indicate that iron's solubility in bismuth at 500° C is less than 30 ppm. Dynamic corrosion studies show that oxygen must be eliminated from type-347 lines to avoid plugging (*3*).

Material for these tests. Inter-

To prove feasibility of salt-extraction for removing rare-earth fission products from liquid-metal fuel, an in-pile experiment with an LMFR processing loop is in progress. A series of dynamic equipment and processing studies led to design of the in-pile loop



mediate-chromium steels were not readily available in fabricated forms; the stainless steels were available in such forms and could be welded to give completely-sealed systems. Since the in-pile experiment will run isothermally, no plugging is anticipated. Stainless steel can be used as a structural material even if operating temperatures are raised above 500° C due to use of a salt system having a higher melting point (intermediate-Cr steels subject to external oxidation at higher temperatures).

After only slight penetration was shown in static corrosion tests in both U-Bi solution and molten salt (LiCl-KCl eutectic), it was decided to use austenitic (300-series) stainless steels for the preliminary test loops.

Test results. Dynamic tests run using the loops shown in Figs. 2–5 indicate that type-347 stainless steel is satisfactory for use in the in-pile loop, where there is no thermal gradient.

Flow characteristics of the two-phase liquid system were studied in a glass and plastic mockup.

The austenitic stainless steels are attacked transgranularly by the U-Bi solution and some nickel is leached from the steel. The rate of attack is quite low under isothermal conditions (Figs. 2–4). A deposit of iron-chromium alloy is built up in the cold region of a nonisothermal stainless-steel system when the U-Bi has no inhibitor additives and is circulated as slowly as in this test (Fig. 5). U-Bi samples were analyzed by the porous-electrode technique (*5, 6*) because the usually more accurate direct-arc method did not yield reliable results, probably because impurities segregated so that test portion was not representative.

Molten LiCl-KCl eutectic has circulated nonisothermally at 0.1–0.4 gal/min in a thermal-convection harp (similar to one in Fig. 4) for over 5,200 hr without plugging; with maximum hot-leg temperature held at 575° C, the cold leg is at about 420° C. Thus, type-347 stainless steel appears to contain the molten salt satisfactorily.

PROCESSING EXPERIMENTS

The loop in Fig. 4 was used to test the salt-extraction process.

Satisfactory sampling and analytical procedures were required for determining the concentration of uranium in bismuth. Since the uranium concentrations were all less than 2,000 ppm, special techniques had to be developed.

Sampling and analysis. The thief-type sampling device shown in Fig. 3 proved most successful. It was necessary to line the sampling rod with graphite when taking samples to be analyzed for constituents of stainless steel, but this was not necessary for uranium determinations.

Concentration of uranium in a sample was determined polarographically. The entire sample was dissolved in nitric acid, diluted, and bismuth precipitated as oxichloride by addition of hydrochloric acid. The filtrate was evaporated to dryness, and the residue was taken up by a supporting electrolyte that is a sulfate-bisulfate buffer with hydroxylamine added to reduce any iron. Uranium quantity was determined by comparing polarographic readings to those of known solutions.

First processing run. The loop was initially charged with enough uranium to reach about 600 ppm in bismuth. After 2,000 hr of operation the concentration had reduced to about 200 ppm. After 2,350 hr of operation, sufficient additional uranium was added to the loop to bring its concentration to 600 ppm. Figure 6 shows how the uranium concentration dropped rapidly to about 300 ppm, where it appeared to remain fairly stable. This removal of uranium from the bismuth indicates either a reaction with the container wall or third-phase formation.

After 3,000 hr of operation the molten LiCl-KCl eutectic was added to the

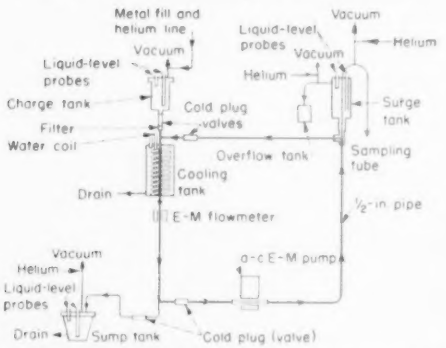
loop's surge tank. Prior to fusion, the salt eutectic was carefully dried under vacuum to remove any water present. This treatment did not, however, preclude formation of some hydroxide due to hydrolysis of the salt. The fused salt was filtered through a porous stainless-steel filter before being added to the loop.

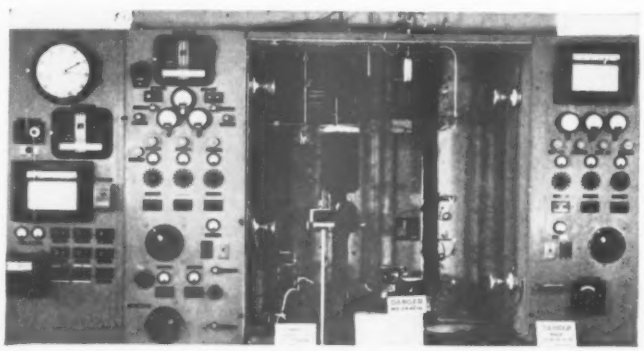
Concentration of uranium in bismuth declined very rapidly after the salt was added. In fact, after approximately 200 hr nearly all the uranium had been removed from the metal. When additional uranium was added to the metal, with the salt remaining in the loop, the uranium was again removed from the metal.

The salt in the surge tank was removed, and additional uranium was added to the metal. After the uranium concentration in bismuth had stabilized, salt was added to the loop. The uranium was again removed from the bismuth. The samples of the salt were taken (by the same method used for the bismuth) and analyzed polarographically. Although the results were somewhat erratic, all samples showed high uranium concentrations in salt.

Samples of the salt from the loop were fused and filtered under high vacuum. The filtrate was found to be nearly free of uranium while the residue consisted of uranium dioxide. Thus, it appears that the behavior of the uranium in the loops that was so different from that observed in test-tube experiments was due to oxygen contamination in the loop. The presence of UO_2 as a third phase in salt accounts for the scatter of the salt analyses since this

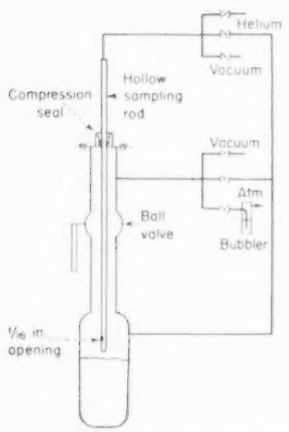
2. Out-of-pile equipment tests show that while isothermally-circulated U-Bi slightly corrodes type-304 stainless steel . . .



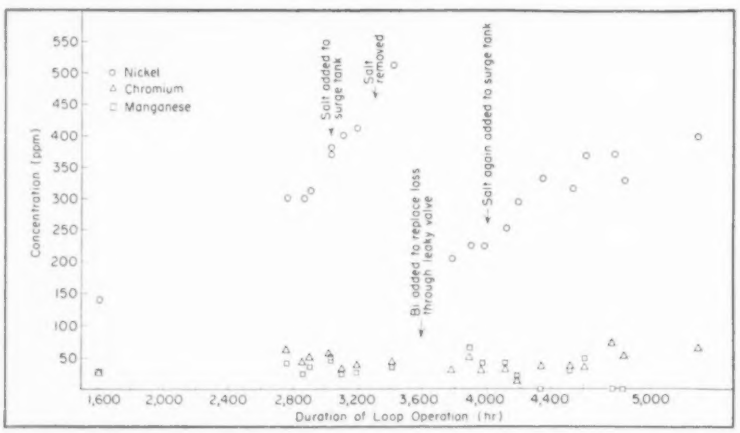


AFTER U-Bi WAS PUMPED through system for 2,400 hr at average rate and isothermal temperature of 1 ft/sec and 450° C, the all-welded type-304-stainless-steel loop (with a type-347 pump cell) was shut down for inspection. As there was no plugging, it is concluded that isothermal operation avoids mass transfer. Bismuth did not erode any sharp edges at elbows or sockets. Type-347 stainless steel in pump cell showed no carbide precipitation and only negligible penetration except at rivet welds (rivets not used in later designs). However, type-304 stainless suffered slight intergranular penetration ($\sim$ 1 mil) and carbide precipitated at grain boundaries

3. Concentrations of type-347's constituents in U-Bi specimens removed . . .

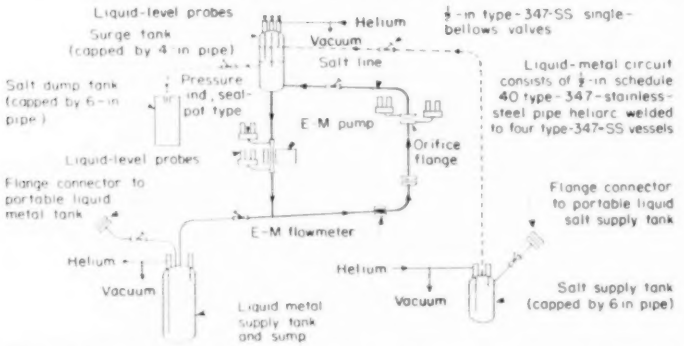


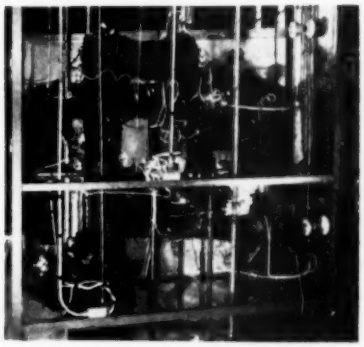
U-Bi SAMPLE IS OBTAINED by inserting the hollow graphite-lined stainless-steel tube, sealed at one end, through the air lock while maintaining He pressure inside tube; sample is drawn into tube when pressure is equalized; tube is removed through air lock; sample is analyzed for stainless-steel by porous-electrode technique (5, 6)



ALTHOUGH LOOP IS STILL OPERATING, some idea of degree of corrosion can be obtained from the amounts of container's constituents dissolved in the Bi. Data is for period before Mg and Zr were added to Bi. Manganese and chromium concentrations remained less than 75 ppm; scatter in concentrations is probably due to detectability limitations of analysis. Iron was not detected ($<$ 30 ppm). Data indicate that isothermal corrosion of type-347 stainless steel is largely a process of nickel being leached from steel. On basis of weight of nickel dissolved, and on assumption that all of it has leached from corrosion areas, penetration after 3,400 hr is calculated as about 2 mils

4. From still-operating isothermal loop indicate satisfactory performance if there is no . . .

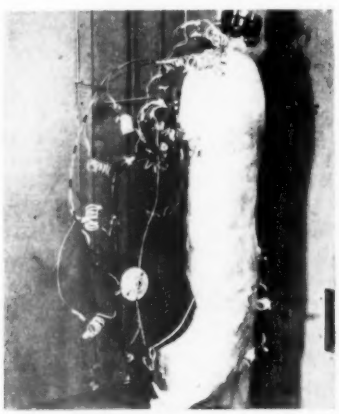




CORROSION DATA are incomplete because this loop, whose main circuit is about 3 ft across and 2½ ft high, is still isothermally circulating U-Bi at 0.6–1.25 gal/min after more than 14,000 hr. Lack of plugging or leaks indicates that type-347 stainless steel can be used in experimental equipment operated isothermally. A static layer of molten salt can be maintained above Bi in surge tank, thus allowing loop to be used for processing experiments. Fill tanks were charged with filtered molten salt and metal. Salt and Bi were added to surge tank at intervals (shown in Fig. 6). Type-G3 GE a-c electromagnetic pump performed satisfactorily until it failed at 4,440 hr because of poor electrical contact between one pump-cell lug and pump busbar. This was caused by severe oxidation. Trouble was corrected by using copper leads to bypass current through outer lug surfaces and contact faces. Pump's efficiency was low (0.06% at 0.4 gal/min; 0.16% at 1.8 gal/min) because of relatively-thick pump-cell walls, Bi's high resistivity, and the fact that pump was designed for use with Na. Electromagnetic flowmeter was calibrated with orifice in line. Elrod's theoretical equation fits data closely (4)

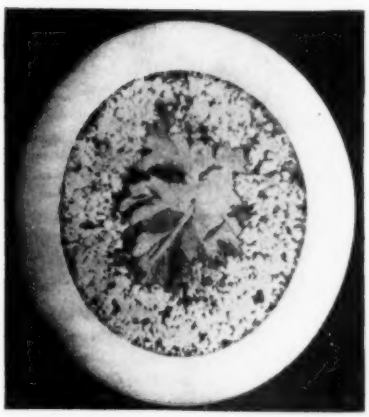
5. Mass transfer and plugging caused by a thermal gradient; and . . .

GAMMAGRAPH SHOWS 1½-in. plugged region along bottom of cold leg



Average analysis of U-Bi samples from various portions of loop shows 30 ppm Fe, 1,900 ppm Ni, 240 ppm Mn, and 65 ppm U. As other studies indicate that large Ni concentrations decrease the solubility of U in Bi, it seems probable that the large amounts of Ni and Mn decreased U from initial 540 ppm.

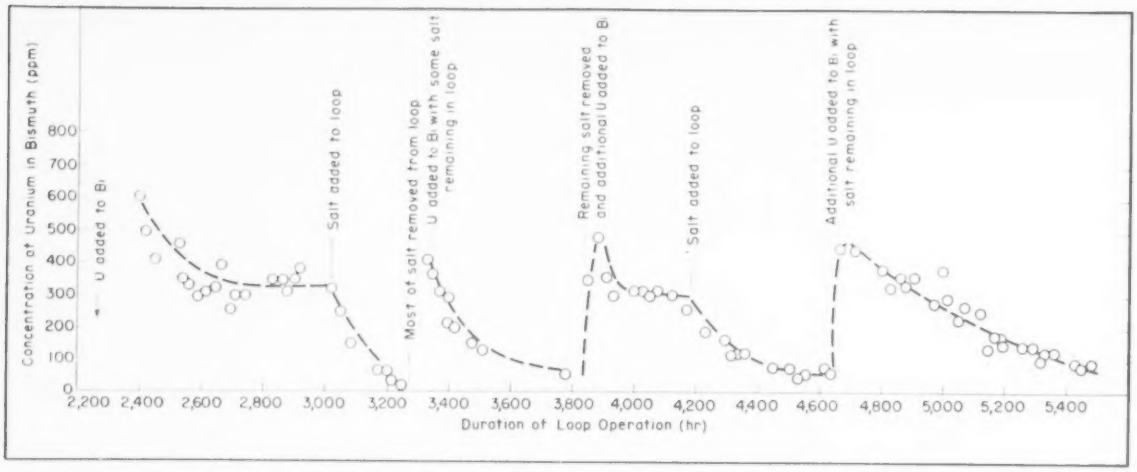
Bi was removed from transverse section of hot leg's machined test section; examination of pipe showed transgranular penetration.



THERMAL-CONVECTION APPARATUS of 1½-in. schedule-40 type-347 stainless-steel pipe formed loop 1 ft across and 2 ft high. All pieces were electropolished before being Heliarc welded; a carefully-machined test section was in hot leg. Heating insulated leg of loop to 615° C caused U-Bi to circulate at 0.2–0.4 ft/sec with initial temperature gradient of 165° C. Gradually-accelerating temperature decrease occurred in cold portion until, after operating 1,200 hr, decrease became very rapid—loop was shut down when cold-leg temperature reached 340° C

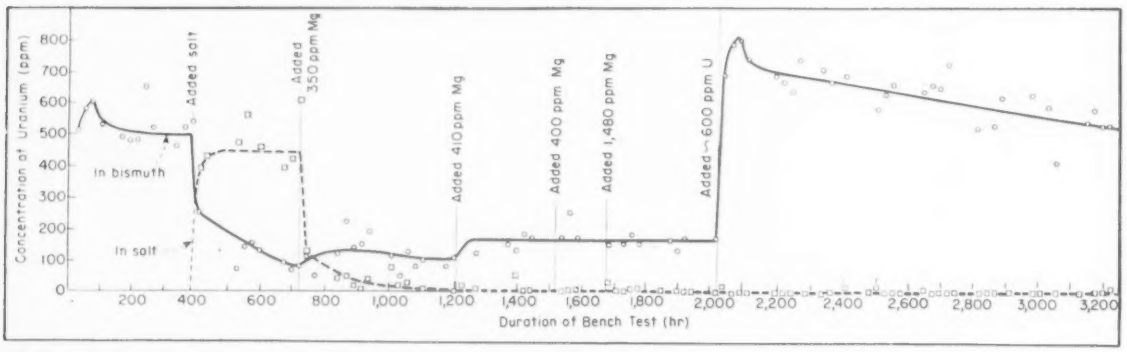
ANALYSIS OF MATERIAL in a transverse plug section shows that it contains 76% Fe, 22% Cr, and small amounts of Ni, Bi, and U. Plates in Bi core are uranium-bearing material, probably U_3Bi_2. Analysis of part of hot leg's test section showed average penetration of 5 mils

6. Out-of-pile engineering-scale processing studies show uranium's removal from bismuth . . .


Concentration of Uranium in Bismuth (ppm)
U added to Bi
Salt added to loop
Most of salt removed from loop
U added to Bi with some salt remaining in loop
Remaining salt removed and additional U added to Bi
Salt added to loop
Additional U added to Bi with salt remaining in loop
Duration of Loop Operation (hr)

VARIATION of uranium concentration in test loop's bismuth

7. Can be prevented by adding magnesium or . . .



BENCH TEST SHOWS how uranium concentration varies when magnesium is added to remove oxygen from system

third phase is probably not dispersed uniformly.

Rare-Earth Distribution

Although the loop was found to be contaminated with oxygen, it was deemed advisable to conduct some rare-earth distribution experiments.

In these runs a small quantity of irradiated rare earths consisting of neodymium, praesodymium and lanthanum, were dissolved in the metal with the salt removed from the loop. The molten salt was returned to the surge tank and the decline in the activity of the bismuth was observed.

In both tracer runs the activity observed by the counter seeing only the bismuth phase was reduced to background within 12 hr after the salt was added (initial activity ≈ twice background). The ratios of the concentration of rare earths in the salt to the concentration of rare earths in the bismuth were 60 to 1 when 5 ppm of rare earths were present in the bismuth and 25 to 1 when 18 ppm of rare earths were in the bismuth. These results are in good agreement with the data of Bareis *et al.* (p. 16).

Several test-tube experiments were run in which lithium hydroxide was added to the salt. These experiments were conducted using methods described on p. 16, except that the salt was not filtered prior to analysis. In these runs, nearly all the rare earths were found in the salt. These results appeared to coincide with those of Bareis *et al.* at the higher concentrations.

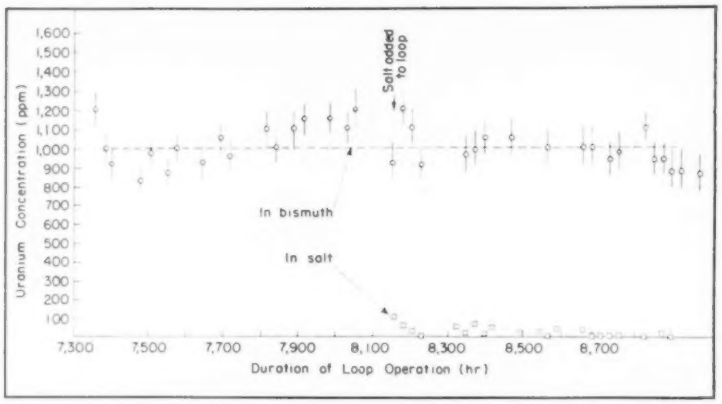
This explains the apparent agreement, insofar as rare-earth distributions are concerned, between loop experiments where oxygen contamination was known to exist and earlier test-tube work. In the runs in which lithium hydroxide was added to the salt, it was found that the uranium was almost quantitatively removed from the bismuth. This agrees with the loop.

Oxygen Getters

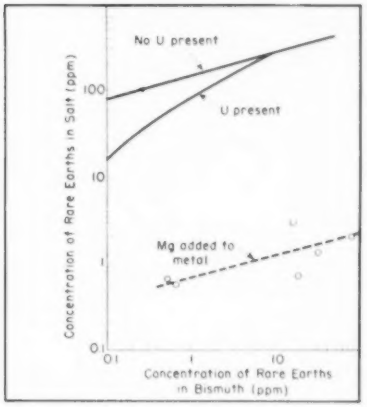
To prevent uranium from being transferred from bismuth to the salt as oxide, it was necessary to take steps to remove oxygen from the system. The most promising method involved using a getter. The metal chosen for this task was magnesium since its oxide is more stable than uranium's.

To determine the method's utility, a bench-scale experiment was conducted. A small stainless-steel pot was filled with molten U-Bi solution. After 380 hr of operation, when the uranium concentration had stabilized at about 500 ppm, the molten LiCl-KCl eutectic was added to the uranium.

8. Magnesium and zirconium



URANIUM CONCENTRATION remains relatively stable in loop whose bismuth also contains zirconium and magnesium



TEST-TUBE EXPERIMENT shows effect of Mg on rare-earth distribution (upper two curves from p. 16)

As was expected, the uranium was removed from the bismuth, and large quantities appeared in the salt (Fig. 7).

After 720 hr of operation, 300 ppm of magnesium were added to the bismuth; concentration of uranium in the salt rapidly dropped to less than 50 ppm, while concentration of uranium in bismuth rose to over 100 ppm. An additional 410 ppm of magnesium added after 1,200 hr of operation raised uranium concentration in the bismuth to 160 ppm, after which it remained constant despite further Mg additions.

This experiment demonstrated that uranium oxide in the salt could be reduced by magnesium. The final uranium concentration in bismuth of 160 ppm is considerably lower than the initial concentration of 600 ppm. This is somewhat perplexing, but reaction with the container might account for it.

After 2,000 hr of operation, sufficient uranium was added to the bismuth in the bench contactor to bring the uranium concentration up to 800 ppm. The concentration of uranium in the metal fell rapidly to about 700 ppm and then declined very slowly so that after 3,5000 hr of operation it had reached 500 ppm. Throughout this period almost no uranium was found in the salt. This decline of the uranium concentration in the bismuth could be due to reaction with the container wall.

Buffered Systems

Before rare-earth distribution experiments were performed in the loop, bismuth and salt remaining from previous runs were removed. The loop was then charged with molten bismuth to which approximately 1,000 ppm magnesium and 250 ppm zirconium were added. Zirconium was added to inhibit the reaction that might take place between the uranium and container walls. Experiments by the metallurgy group at BNL indicate the value of such inhibitors in loops of intermediate chromium steel. It was hoped that a similar effect would be obtained in type-347 stainless steel.

Figure 8 shows the time variation of uranium concentration for this run. Uranium concentration in bismuth remained relatively stable throughout the experiment even with salt present. A concentration of about 1,000 ppm was maintained in Bi without any significant losses to container or salt.

Although the addition of magnesium metal was extremely useful in preventing transfer of uranium to the salt phase, its presence alone should inhibit transfer of rare earths. If no magnesium chloride is present in the salt

$$Mg + 2\,LiCl \rightleftharpoons MgCl_2 + 2\,Li$$

should produce sufficient quantities of free lithium to force the reaction

$$Ce + 3\,LiCl \rightleftharpoons CeCl_3 + 3\,Li$$

left and retain rare earths in metal.

Figure 8 shows the results of test-tube experiments where magnesium metal was added to the bismuth. The rare earths were retained by the metal, as would be predicted by the theory of Bareis *et al.* However, this cannot be regarded as conclusive proof of their explanation; if the interphase transfer was due to oxide formation, the addition of magnesium should have the same effect as that observed.

Bareis *et al.* have suggested (p. 16) that the problem of sensitivity to oxidizing impurities could be overcome by using a buffered system where the oxidation potential is not greatly changed by oxidation of a small amount of material. Adding the proper metal: metal-halide or -oxide to the bismuth: LiCl-KCl system should allow the oxidation potential to be held at a point where the rare earths will be oxidized with the uranium remaining in the reduced metallic state. The system where magnesium is added to the metal and $MgCl_2$ to the salt may be satisfactory since available thermodynamic data indicate that the oxidized state of magnesium is less stable than the oxidized state of the rare earths, but more stable than the oxidized state of uranium. Experiments are now being conducted in the loop to determine the effect of the Mg-$MgCl_2$ system on rare-earth distribution.

* * *

The authors wish to acknowledge the assistance of many people in BNL's nuclear engineering department without whose assistance the study could not have been made. Special thanks are due to D. Bareis, R. Bauman, A. Friedland, L. Hersh, H. Susskind and C. Waide for their work on the design and operation of the experiments.

BIBLIOGRAPHY

1. M. A. Cordovi, BNL-179 (1952)
2. O. J. Elgert, C. J. Egan, MTA-12 (1953)
3. J. F. Collins, NEPA-1800 (1951)
4. H. G. Elrod, technical report I (Babcock and Wilcox Co., New York, 1950)
5. C. Feldman, *Anal. Chem.* **21**, 1041 (1949)
6. J. C. Delaney, L. E. Owen, NEPA-1474-SCR-59 (1950)

LMFR PART V

A Continuously Separating Breeder Blanket Using ThF_4

Continuous removal of UF_6 from a fixed bed of ThF_4 is possible, but gas cooling of the bed is difficult. A similar process conducted outside the reactor looks more promising, also lessens corrosion problem

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Upton, New York

To KEEP FUEL COSTS low in a power reactor, fissionable material must be bred. This article describes development of a breeding blanket that produces U^{233} from thorium by neutron capture and that incorporates the chemical processing necessary to separate U^{233} from thorium.

In this breeder, the fertile material is thorium fluoride. Uranium and protactinium formed by neutron capture (Fig. 1) are removed by volatization of the fluorides in the presence of excess fluorine, as suggested by the discoverers of U^{233}, R. W. Stoughton and G. T. Seaborg.

The simplest continuously separating blanket form would be a bed of fine-particle thorium fluoride cooled by passage of a fluorine-containing gas. As Pa^{233} and U^{233} were formed, the atoms would diffuse to the surface, where they would be fluorinated to PaF_5 and UF_6. Both are more volatile than the high-melting thorium fluoride; they would be removed in the cooling gas stream and condensed out in a cold trap outside the reactor.

A workable process depends on rapid enough diffusion of U or Pa through the thorium fluoride and on preparation and maintenance of fine enough thorium fluoride particles at the necessary temperatures. The first goal of the experimental program, therefore, was determination of diffusion rates as a function of physical and chemical composition of the thorium fluoride, extraction temperature, extracting-gas composition, and other variables.

Preliminary Studies

Apparatus was set up for exposing small neutron-irradiated fluoride samples to a metered flow of fluorine-containing gas at controlled temperatures up to 700° C. Any Pa or U extracted and carried downstream as a volatile fluoride was collected in a trap and measured. Absolute analyses were not required; the interesting quantity was the ratio of amount removed to that originally present in the solid. A study of this variable as a function of time was expected to, and did, throw much light on the mechanism involved.

The gamma activity of the protactinium used for the bulk of the kinetic studies made a simple experimental technique possible. The cooled tube section where protactinium fluoride condensed out was placed in the sensitive region of an ionization chamber. An electrometer was used to measure, a strip chart to record, gamma-ray ionization and thus relative amount of Pa removed from the sample.

A continuous record could not be obtained with uranium. Instead, points on the fraction removed vs time curve were obtained at intervals by washing deposited uranium out of its trap and analyzing the resulting solution.

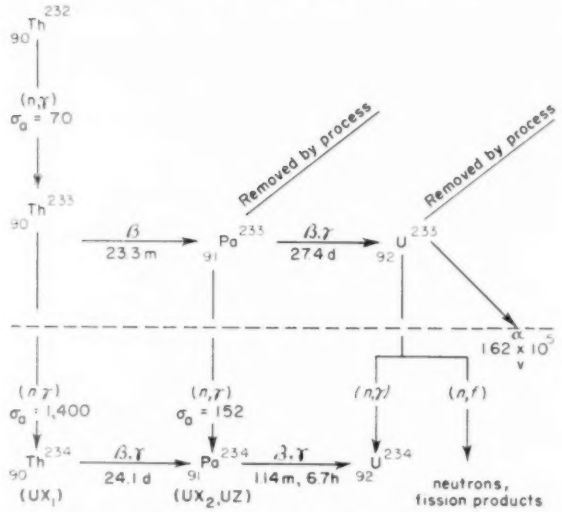
The thorium fluoride used usually consisted of a fine powder compressed into 2–4 gm pellets for convenient handling. Sufficient protactinium activity was produced in such a pellet by a few minutes' irradiation in the Brookhaven reactor. For uranium tracer, about 100 times as long an irradiation was used, followed by 6 months' storage to allow protactinium decay.

Results. The first experiments done confirmed at least the chemical possibility of the proposed separation (Fig. 2). Activity disappeared from the pellet and accumulated in the trap; thorium fluoride itself did not distill at all.

Protactinium transfer unexpectedly required the high temperature of 500° C. Evidently PaF_5 has a very low volatility; this was confirmed by dynamic vapor-pressure measurements.

The kinetics of tracer removal were, to a first approximation, characteristic of a process controlled by diffusion through a solid. The slow step is diffusion of a Pa or U atom, formed by neutron capture in the interior of a thorium fluoride crystallite, to the crystallite surface. There it is oxidized to its highest valence, as volatile fluoride.

1. Continuous removal process for breeder can meet . . . these blanket requirements



NUCLEAR REACTIONS involved in breeding U^{233} from Th: Natural Th captures neutron to form Th^{233}. Two successive beta decays form fissionable U^{233}. Side reactions waste neutrons, make undesired products below dotted line

A Neutron economy must allow a breeding gain. Neutron-capturing nonbreeding materials must be limited so that breeding gain does not fall below that necessary to replace material burned in reactor core. Since thorium has a cross section of 7 barns, all but lowest cross section materials must be excluded from blanket.

B Blanket arrangement must allow cooling. Heat production in the blanket may be anything from a few per cent of that in core to much larger figure if uranium is allowed to build up. The necessity of cooling favors a circulating blanket over a gas-cooled fixed bed.

C A process is needed to remove Pa^{233} and U^{233}. Frequent processing reduces wasteful capture by Pa^{233}, fission of newly formed U^{233} that adds to heat load, and to production of fission products that capture neutrons wastefully.

D Operation and chemical costs cannot be too expensive, especially in a power reactor.

and carried away relatively quickly.

Such a model calls for the fraction removed to be dependent on the square root of the time until about 20% of the charge has been removed, providing the ultimate particles are nearly uniform in size. Curve *A* in Fig. 2 shows that this law is followed approximately over a wide range. The diffusion model is further supported by the observed temperature coefficient of the extraction rates, 40–60 kilocuries/mole; by the dependence of removal rates on thorium-fluoride particle size; and by the lack of dependence of diffusion constant on tracer depletion. That is, if a sample depleted of tracer during a run is reirradiated to produce more protactinium, diffusion properties deduced from removal kinetics remain unchanged. It follows that tracer atoms were randomly distributed through a homogeneous medium; all atom sites were equivalent.

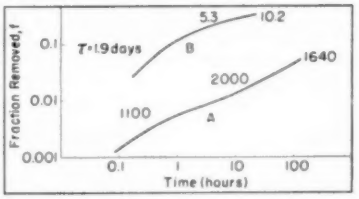
Close examination showed that most curves deviated from strict adherence to diffusion kinetics in two ways. In the earliest stages of a run, removal rate was more nearly proportional to t than to $t^{1/2}$. At longer times a divergence occurred, indicating a decrease in diffusion constant or a coalescence of small particles into larger ones. The first effect can be explained by a temporary hold-up of material at the solid-gas interface caused by protactinium's low volatility; it is not of practical importance.

The second effect is serious. It was not unexpected; the tendency of powdered materials to sinter at elevated temperatures is well known.

In an attempt to anticipate this effect, thorium fluoride samples were pretreated at temperatures higher than those used during extraction. These samples followed diffusion kinetics exactly, but all rates were much too low for a practical process. Any acceptable extraction rate, whether obtained with high temperatures or very fine particles, produced "sintering;" that is, diffusion properties deteriorated until no longer acceptable.

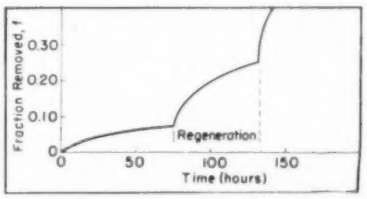
A numerical example may be inter-

2. Possibilities of process were shown by tracer test, and . . .



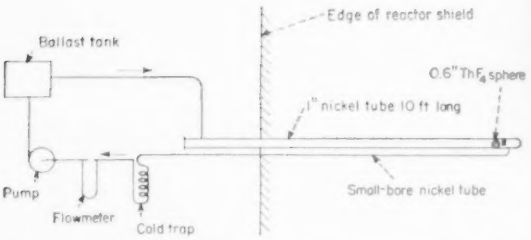
CHEMICAL FEASIBILITY of continuous removal of bred material was demonstrated by removing Pa tracer in F_2-N_2 process gas. Log fraction removed plotted against log time here for typical run confirms kinetics characteristic of process controlled by diffusion through a solid (curve *A*). Deviation from theoretical curve in early stages is not important, but falling off after 10 hr in curve *B* indicated sintering interfered with removal. Values of τ, the mean hold-up time, indicate process usability; low τ values are aim

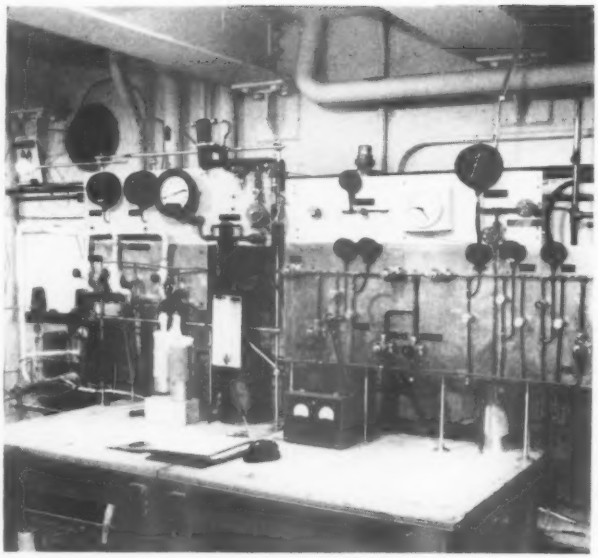
3. Regeneration promised to solve main problem, sintering, so . . .



REGENERATION to counteract sintering involves hydrolysis of thorium fluoride to oxide followed by reconversion to fluoride; extraction behaviour before and after regeneration at two discrete times is shown. Pellet was alternately exposed to 500° steam and 300° anhydrous HF. Drastic reduction of effective particle size was reflected both in increased surface area and accelerated tracer extraction. Heavily sintered pellets required two or three applications of cycle; cumulative effect gave powder equivalent to best virgin material

4. In-pile apparatus was built for further studies. But . . .





IN-PILE REACTION VESSEL is 1-in. nickel tube extending into reactor to point where neutron flux was about 1×10^{12}. Reaction-zone is 400° or a little higher—not high enough to volatilize PaF_5—so results are obtained with U. Fluorine corrosion, geometry and temperature sensitivity of experimental hole prevent higher temperatures. Fluorine-helium mixture passes over ThF_4 sphere, leaves reactor through small-bore nickel tubing heated uniformly to 200° to prevent adsorption of UF_6. Outside, gas passed through liquid-oxygen traps that collected UF_6 and other nonvolatiles. Process gas is recirculated constantly. Traps are removed periodically and analyzed for uranium

esting. It is convenient to express the quality of a thorium fluoride preparation, at a given temperature, in terms of its "mean hold-up time," τ. This is the mean time elapsing between formation of an atom of Pa or U and its removal from the thorium matrix in a continuous in-pile process; it can be derived from observed tracer-experiment kinetics.

Values of τ of the order of 30 days were the goal of this research. In a characteristic run, a powder that received pretreatment for 2.5 hr at 650° C was extracted with fluorine at 600° C; the data yielded a τ value of about 100 days. Another specimen of the same material was run at 700° C. A τ of 1 day was first observed, but after 200 hr it had increased to 44 days and showed no signs of leveling off.

Use of a wide variety of preparations over a wide temperature range showed that the slowest sintering rate giving an acceptable value of τ occurred with 600° extraction of a fine-particle (< 1 micron) powder.

Uranium extraction work generally confirmed protactinium results; kinetics were those of sintering-modified diffusion, and absolute rates were comparable. With uranium, however, the hexafluoride's greater volatility permitted removal at temperatures below 500°. With sufficiently fine particles, acceptable τ values were obtained as low as 400°. These preparations were subject to sintering like the others.

An attempt was made to correlate change in extraction properties with decrease in surface area, as measured by nitrogen adsorption. Thorium fluoride powders in the micron range lose area markedly when heated at 600° or higher in an inert atmosphere. Measured surface area changed much more slowly than did the extraction rate, however. The decreased rate may be caused by annealing out of small cracks or imperfections in the crystallites; these cracks serve as diffusion channels but do not contain areas open to nitrogen adsorption.

Regeneration

It became clear that the blanket process as originally conceived would not work unless the sintering process could be reversed. Various expedients were tried; the best—hydrolysis of ThF_4 to oxide and reconversion to fluoride—gave the results shown in Fig. 3.

Like all high-area material, the regenerated fluoride is still liable to sintering. In breeder-blanket operation, regeneration would have to be repeated monthly. It could be done simply enough *in situ* by remote control, since only gases are to be manipulated, and it would be cheap. Temperature dependence of hydrolysis-hydrofluorination equilibrium is such that a scheme can be worked out in which no HF will be lost or even diluted to the point where concentration equipment would be needed.

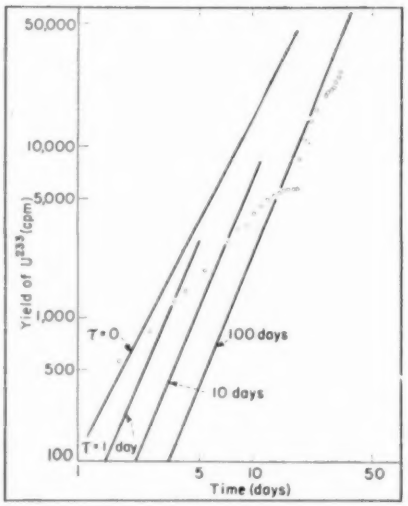
One serious disadvantage to the cycle is the unprecedented corrosion problem. The blanket container would have to withstand exposure to alternate atmospheres of fluorine and two different steam-HF mixtures. The very cycle that "regenerates" thorium fluoride would destroy the fluoride film that protects metals from serious attack by fluorine. A few metals, however, form fluorides that are very resistant to hydrolysis and are not attacked by HF-H_2O mixtures that hydrolyze thorium fluoride. Magnesium is one of these; it would probably be possible to develop a construction material using magnesium fluoride in ceramic form or as an impervious coating on a metal.

In-Pile Studies

Tracer-scale extraction results seemed good enough to justify construction of in-pile apparatus to simulate breeder-blanket conditions more closely. See Fig. 4.

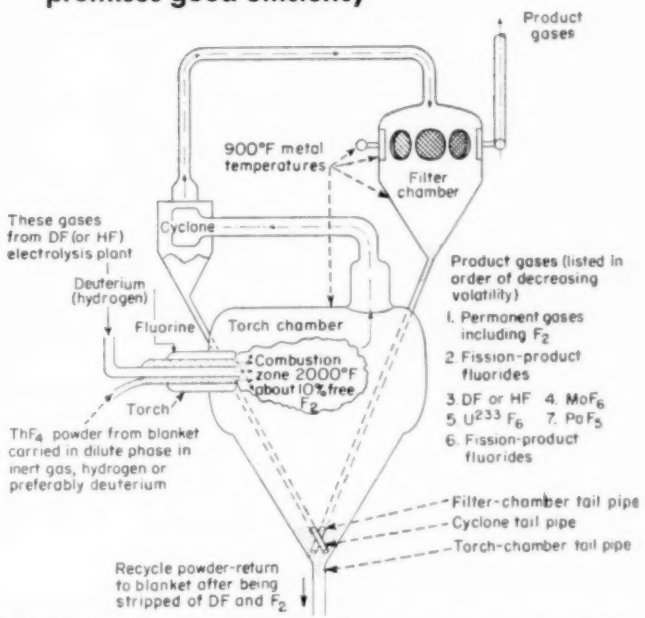
The main difference from laboratory conditions is the constant exposure to reactor radiations during fluorine extraction. It was hoped that the resulting radiation damage would accelerate diffusion. Unfortunately, this was not

5. In-pile results also show sintering. This lead to . . .



IN-PILE RESULTS CONFIRM laboratory tracer experiments. Solid lines show removal calculated for diffusion-controlled rate without sintering. Circles are observed removal, indicate adverse affect of sintering. Radiation damage does not help as expected. Instead, τ values are larger than in laboratory; at 400° not even submicron powder had acceptable extraction rate. Extrapolation from 325° and 400° results gives minimum adequate operating temperature of 500°. In-pile runs also confirmed tracer studies of regeneration and reduction of τ value by incorporating small quantities of SrF_2 in ThF_4

6. Modified process with external removal that promises good efficiency


Product gases
900°F metal temperatures
Filter chamber
These gases from DF (or HF) electrolysis plant
Cyclone
Deuterium (hydrogen)
Fluorine
Torch chamber
Combustion zone 2000°F about 10% free F_2
Torch
ThF_4 powder from blanket carried in dilute phase in inert gas, hydrogen or preferably deuterium
Product gases (listed in order of decreasing volatility)
1. Permanent gases including F_2
2. Fission-product fluorides
3. DF or HF 4. MoF_6
5. $U^{233}F_6$ 7. PaF_5
6. Fission-product fluorides
Filter-chamber tail pipe
Cyclone tail pipe
Torch-chamber tail pipe
Recycle powder-return to blanket after being stripped of DF and F_2

TORCH BURNS hydrogen with excess fluorine to melt thorium fluoride powder momentarily in fluorine atmosphere. Corrosion problem is minimized by keeping flame away from chamber walls. Thorium fluoride freezes in form of small spheres and settles out; gaseous Pa and U fluorides go to cold trap where PaF_5 is condensed. UF_6, F_2, HF, fission-product fluorides, etc., continue to series of distillation columns for separation and purification. Pa in trap decays; $U^{233}F_6$ formed is carried off in stream of fluorine. Laboratory-scale test with inefficient torch recovered ThF_4 spheres similar to feed, but with as little as 15% original Pa activity. Spheres were suitable for recycling to a gas-fluidized blanket. Cold traps collected up to 30% of Pa activity without Th

the case. See Fig. 5. But regeneration was possible.

Design Limitations, Solutions

Although tracer and in-pile studies demonstrated the process, design of a thorium fluoride blanket appears difficult because of the heat removal problem. Our present ideas on the core of an efficient power reactor require that it operate at a high power with a high leakage of neutrons. This puts a larger heat load on the blanket than can be removed in a circulating gas. The idea of a stationary bed must be abandoned in favor of moving the bed to an external heat exchanger.

Another difficulty is corrosion. Introduction of the regeneration process with steam and HF as well as fluorine produces an extreme corrosion problem that must be met with materials of low neutron cross section. But removing the thorium fluoride from the reactor for cooling also moves corrosion problems to the point where they need not be solved simultaneously with the neutron economy problem.

This leads to consideration of some modified blanket forms. In the simplest, the thorium fluoride would be handled as a fluidized bed. This bed could be circulated to an external heat exchanger for cooling. As often as necessary, part of the powder could be bypassed to a processing plant for extraction with fluorine. The blanket now need contain only an inert gas, and this could be operated at reasonably low temperature to ease corrosion.

The process outside the reactor could now be operated at a much higher temperature, giving rapid uranium extraction. At a temperature above the thorium fluoride melting point, diffusion is rapid enough for immediate removal of Pa and U. Extreme corrosion problems are avoided with a torch like that shown in Fig. 6.

Another possible modification of the externally cooled and processed blanket is a slurry of thorium oxide or fluoride in heavy water. This would be easy to cool by circulation to an external heat exchanger. The oxide could be processed by a combination of regeneration steps and fluoride extraction; the fluoride, perhaps, by extraction in the torch alone.

Although these blanket schemes are not as elegant as the original proposal where only those atoms that had captured neutrons would be removed from the blanket, they may offer a blanket and process that meets requirements of neutron economy, cooling, frequent processing, and economic operation.

An alternate blanket being considered also, is a dispersion of thorium bismuthide in liquid bismuth (see p. 12).

* * *

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LMFR PART VI

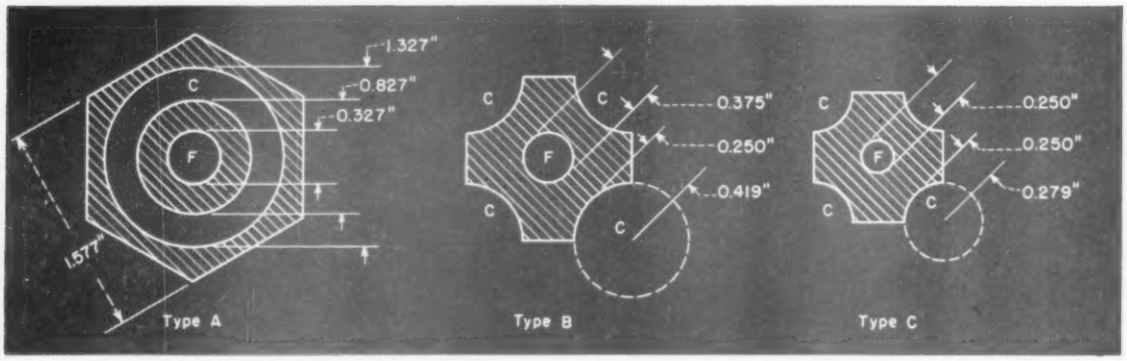

FIG. 1. Three core-element designs for internally-cooled LMFR. Fuel flows in the areas marked F; coolant flows in areas marked C

Heat Exchange in LMF Power Reactor Systems

Underlying principles and factors affecting design of heat transfer components in LMFRs are discussed. Calculations are presented for typical system designs

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To KEEP REACTOR SIZE and fuel inventory down within reasonable limits, high heat fluxes are necessary in the heat-exchange components of nuclear power reactors. For such high-flux, high-temperature heat transfer, liquid metals find particular application, because of their high thermal conductivities and low viscosities and vapor pressures.

In all power reactors, but more particularly those externally cooled, core design and size and such important reactor characteristics as fuel inventory, burnup time, specific power, and—in the case of breeders—doubling time, are controlled more by heat-transfer than by nuclear considerations. Thus, a compromise between these two normally opposing factors must be reached.

Since the production potential of bismuth, the main constituent of the LMFR fuel mixture, makes it not unlimited in availability, it is important to minimize the "fuel" requirements for the sake of the bismuth as well as the fissionable material it carries. Thus, in the design of the heat-transfer equipment described here, an attempt was made to keep the fuel inventories as low as possible. This called for high heat fluxes in exchangers and low holdups in isothermal system parts.

HEAT TRANSFER PROBLEMS

Heat removal consists of two phases: heat transfer and heat transport. The former is the transfer of energy from the material being cooled to the one being heated; the latter refers to the transportation, by some fluid, of the energy from one point in the system to another. Either of these steps can be limiting in power-reactor design; the importance of heat transport cannot be overemphasized.

Neutron Economy

Because neutron economy is critically important in thermal breeder reactors, the carrier metals in the fuel mixture and primary coolant (in internally cooled reactors) must have low absorption cross sections.

Bismuth, with a 0.030-barn thermal-neutron absorption cross section, is the best coolant and carrier metal for the fuel. It has a relatively low melting point and can dissolve appreciable amounts of uranium. In the internally cooled reactor designs discussed here, the primary coolant is also the breeding mixture. It is bismuth that contains a suspension of thorium bismuthide.

In thermal breeders (reactors "burning" and producing U^{233}) the number of neutrons produced per neutron absorbed is such that relatively few neutrons can be allowed to be captured by nonfertile or nonfissile materials, even for the case where the reactor produces only as much uranium as it consumes. Thus, the problem of neutron economy is a very real one and the need for low-cross-section metals as carriers for fertile and fissile materials and as primary coolants is indeed

pressing; and in this discussion, both fuel and primary coolants are taken to be straight bismuth, neglecting the other materials in it, for heat-transfer purposes.

Corrosion

Bismuth dissolves most structural metals to a degree dependent on temperature. In a nonisothermal cyclic-flow system, bismuth can dissolve container material at the high-temperature parts of the system and precipitate it (usually as intermetallic compounds) in low-temperature zones. This process of material transfer is commonly referred to as "mass transport." The corrosion products can build up to the point where they plug flow channels and conduits.

The process can be reduced to a tolerable degree by: 1, using a container material that has a very low dissolution rate; 2, adding corrosion inhibitors to the liquid metal; and 3, flowing the liquid metal fast enough to keep corrosion products in suspension.

Corrosion forces the use of structural materials with inferior physical properties and heat-transfer characteristics. In the designs considered here, graphite is used inside the core and Croloy 5-Si* is used outside the core. Their lack of nickel seems to make Croloy ferritic steels better than regular stainless steels for minimizing the problem of mass transfer by bismuth. Compared to regular stainless steels, however, they have less oxidation resistance at elevated temperatures and generally poorer physical properties.

High-Velocity Erosion

The high coolant velocity needed for efficient heat transport must be compromised with erosion limitations. Since at a particular linear velocity a given volume of liquid bismuth has ten times the kinetic energy of water, it produces high impact pressures at baffles, sharp turns, and pipe bends. The resulting erosion produces the same net result as localized corrosion.

Erosion probably would be worse in container materials that depend on intermetallic layers for protection, particularly where such layers are not sufficiently hard and well bonded.

Unfortunately, very few velocity-erosion data exist for liquid heavy metals flowing in steel equipment and in graphite.

In designs presented here, the erosion problem causes maximum linear velocities to be set arbitrarily at 10 ft/sec for bismuth, and at 25 ft/sec for sodium (the secondary coolant). These limits have not been influenced by pumping-power considerations; pumping power requirements are low.

But, maximum allowable linear velocities directly affect holdup. In flow lines, liquid metal holdup varies inversely as the linear velocity; in heat

* Product of Babcock and Wilcox Co., Tubular Products Div.

Cooling: Internal vs. External

Unlike reactors with solid fuel elements, liquid-fuel reactors can be cooled either internally or externally, i.e., the fuel can remain inside the core and therein transfer its heat to a primary coolant, or it can be continuously circulated to external heat exchangers where it transfers its heat to a secondary coolant. There are certain advantages and disadvantages to each method of cooling, and the choice between them depends on the purpose and design characteristics of the particular reactor.

External cooling gives or permits: 1, smaller reactor core because the fuel is the primary coolant and there is no structure separating fuel and coolant streams; 2, simpler reactor construction and, therefore, fewer thermal-stress problems; 3, heat exchangers having better heat-transfer coefficients; 4, less critical leak problem and greater operating reliability (several exchangers can be operated in parallel, if leaks develops in one, it could be isolated from the system and its load taken by another); 5, rapid fuel circulation permitting prompt removal of gaseous fission products; 6, rapid fuel circulation permitting better control of reactivity (fuel concentration can be changed quickly by adding or removing fissile material as fuel is circulated); 7, secondary coolant having a high cross section; 8, greater design flexibility and fewer restrictions on choice of materials because heat transfer and fission processes are separate.

Internal cooling gives or permits: 1, lower fuel inventory; 2, no radioactive steam because primary coolant flows to steam-generating equipment outside core (with external cooling, an additional heat-exchange circuit would be necessary to do this); 3, secondary coolant that is not radioactive; 4, primary coolant that can also be the breeding stream.

For internal cooling, the structure separating the fuel from the coolant should have: 1, a geometry that provides a large heat-transfer area (without being massive); 2, low thermal-neutron absorption cross section; 3, high thermal conductivity; 4, sufficient strength to prevent cracks and ruptures; and 5, satisfactory resistance to corrosion by high-temperature fuel and coolant.

No such ideal material exists. Several good structural metals are eliminated by their high neutron absorption. Graphite is reasonably good from most standpoints, but is deficient in strength. Graphite tubes are not practical, but fuel and coolant can be circulated in separate channels in large graphite blocks that have a minimum graphite thickness between streams and that provide a sufficient area for heat transfer.

From the neutron-absorption standpoint, bismuth is the best metal available as a liquid coolant. Other low-cross-section metals, such as Li^7 and Pb^{208} would be better, but being isotopes, they would be prohibitively expensive.

From this comparison, it can be concluded that, from an operational standpoint, external cooling might be generally preferred to internal cooling.

Secondary Coolant: Yes or No?

Fission heat can be transferred directly from the liquid-metal fuel (primary coolant) to steam, or an intermediate coolant can be used.

The one great advantage of direct transfer is the elimination of the secondary coolant system with its heat exchanger, coolant, piping, and pumps. The disadvantages of direct transfer are: 1, low over-all coefficients encountered with thick pressurized tubes and superheated steam necessitate large heat-exchanger units and correspondingly large fuel inventory; 2, larger heat-transfer area increases probability of leakage; 3, high thermal stresses in tube walls result from large difference in fuel and steam temperatures in cases where it might be economical to produce steam at temperatures appreciably below the top fuel temperature (a secondary coolant is convenient for stepping down the temperature of the fuel stream at the high-temperature end); 4, steam becomes radioactive—this aggravates steam-plant maintenance, creates need for leak-tight steam and condensate lines, and introduces additional shielding problems; 5, gamma-radiation decomposes steam; this necessitates including an O_2-H_2 recombiner in steam system, and the free oxygen corrodes condensate lines.

exchangers, holdup depends on size, which is a function of heat-transfer coefficients, which in turn depend on linear velocities. Since it is very important to minimize holdups in liquid-metal-fuel reactors, linear velocities must be pushed to the limit.

The results of planned erosion experiments might make it possible to increase the velocity limits indicated above.

Equipment

Heat-transfer components must be highly safe and reliable. They must not be inordinately expensive or have unduly high depreciation rates. In addition, the components should be easily and quickly replaceable.

High temperature and radioactivity of the liquid-metal fuel mixture makes it absolutely necessary that all system parts be completely leaktight, which means all-welded construction. To avoid oxide formation, atmospheric oxygen must be kept out of liquid-metal systems. These oxides immobilize fissile material, reduce heat-transfer rates by surface fouling, adversely affect the operation of pumps, valves, and instrumentation, and when present in excessive amounts, cause plugging of restricted flow passages.

Because of the frequent chemical incompatibility (in some systems) of the fluid being cooled and the one being heated, the heat exchangers must be absolutely tight to cross-leakage. This again calls for all-welded construction; and, in many cases, requires double-wall heat-exchanger tubes with a monitored fluid in the annular space.

Heat-transfer equipment design must provide for thermal expansion. In liquid-metal heat transfer, the problem of thermal stress of the tube wall is particularly serious because of the large temperature drops usually existing across it. In fact, it is these stresses that usually limit the temperature drop (and thus the heat flux).

Pumps must be absolutely leaktight, have low maintenance costs, and be easily replaceable. For alkali metals, electromagnetic pumps are frequently used. These pumps have no moving parts, no seal problem, and no bearing problem; but they cannot be used economically for pumping the heavy metals.

Mechanical pumps of the centrifugal-impeller type are also used and the seal problem is either eliminated entirely as in the canned-rotor design or solved by using a frozen seal. In the latter type, the metal being pumped is allowed to leak around the shaft and there cooled below its freezing point. In certain applications, inert gas seals are permissible.

Estimating Coefficients

The theory of convective heat transfer in liquid metals is far less advanced than that for ordinary fluids; which introduces appreciable uncertainty in design calculations.

In the calculations to follow, film heat-transfer coefficients for turbulent flow of sodium inside circular tubes were evaluated by means of the Lyon-Martinelli equation (*1*)

$$\frac{hD}{k} = 7.0 + 0.025\left(\frac{Dvp\mathcal{C}}{k}\right)^{0.8} \quad (1)$$

For bismuth, the value of h as obtained from this equation was reduced by 30 per cent, since most of the experimental results on the heavy metals seem to fall about 30 per cent below these predicted by the L-M equation, in the Peclet number range of interest in the present study. The Peclet numbers generally exceeded 1,000; if they had been much lower than this, a reduction of 35 or 40 per cent would probably be more appropriate.

This difference between theoretical and observed coefficients has usually been, in part at least, attributed to "non-wetting" of the heat-transfer surface by the liquid metals. This "non-wetting" resistance to heat transfer might be an interfacial resistance between pure liquid metal and a perfectly clean solid surface or the resistance of a third phase interposed between the pure liquid and the clean wall; this third phase being either a gas, or another solid such as an oxide, or a mixture of the two. The majority of experimental evidence to date seems to lend support to the predominance of the "third phase" effect.

The heavy metals, unlike the alkali metals, do not have the ability to reduce surface oxides. Even with good apparent "wetting," however, there is some evidence to indicate that Eq. 1 does not adequately represent the convective heat-transfer process for flow of heavy metals inside tubes, particularly at the lower Peclet numbers.

For bismuth flowing in a ½-in.-ID tube at a Peclet number of 1,000, Eq. 1 indicates that the film coefficient should be 2,940 Btu/hr/ft²/°F. If this value is high by 30%, the true value is 2,060. Assuming this reduction is due to some kind of "contact" resistance, one obtains a contact coefficient of 6,800. At a Peclet number of 100, Eq. 1 gives a coefficient of 1,730; but experimental data indicate that the equation gives coefficients high by a factor of two at this Peclet number. If the difference is due to a contact resistance, the con-

tact coefficient will be 1,730. This means that the contact resistance increased fourfold as the Peclet number was reduced from 1,000 to 100. If this contact resistance is due to an interfacial resistance between pure solid metal and pure liquid metal or the interposition of a third solid phase, such a resistance would not be expected to change appreciably with Peclet number. Thus, this analysis suggests basic disagreement between the equation and experimental heat-transfer results on heavy metals.

To estimate shell-side coefficients for unbaffled shell-and-tube heat exchanger (the only type of external heat exchanger employed), Eq. 1 was modified only by replacing D by D_e. In the designs considered, there was little flow of metal across the tubes.

For sodium, the coefficients as given by Eq. 1 were not changed, because the equation has been fairly well substantiated by experiment for alkali metals flowing inside circular tubes.

There are two other equations that might have been used to evaluate the shell-side coefficients. Tidball's revision (*2*) of Donohue's equation (*3*) was not used here because it was felt that it would give too-high coefficients. Donohue's equation correlated shell-side coefficients on water and oil for unbaffled shell-and-tube exchangers. Tidball's revision correlated experimental results on NaK flowing on the shell side of a baffled exchanger; but the data showed considerable scatter and were obtained in a miniature exchanger in the relatively low Reynolds-number range of 4,000–15,000.

Moreover, Brooks' and Rosenblatt's equation (*4*), based on data for shell-side NaK flow in an unbaffled shell-and-tube exchanger, was not used here because the data were taken in the low (and inapplicable) Reynolds-number range 5,000–80,000, and the coefficients were calculated from over-all heat-transfer coefficients rather than determined directly. At the higher Reynolds numbers, Brooks' and Rosenblatt's data appear to approach agreement with Eq. 1.

The three equations differ greatly in their estimates of shell-side coefficients in unbaffled shell-and-tube heat exchangers. Equation 1, with D_0 substituted for D, was used because it gave the most reasonable results and was applicable to the present designs with the fewest and safest assumptions.

On the basis of preliminary data, Bonilla and Wong (*5*) have reported interfacial coefficients ranging from 150 to 1,500 for unwetted steel and up to 4,000 when small amounts of sodium were added.

Here, the problem of estimating contact coefficients arises for the case where fuel is held stagnant in a graphite channel under assumed wetting conditions. Without much experimental data or supporting evidence, a contact coefficient of 10,000 was chosen. Much expert experimental work will have to be done before contact coefficients can be estimated reliably for liquid-metal:solid interfaces.

The calculated results presented here were obtained assuming that no surface fouling occurs and that no third phase exists to prevent good thermal contact between the liquid metal and the heat-transfer surface. Moreover, no safety factors were introduced. Physical properties of a liquid metal were obtained from ref. (*6*).

Realization of maximum heat-transfer coefficients with heavy liquid metals requires extremely clean systems. The importance of filtering the liquid metal and cleaning the equipment before startup cannot be overly stressed.

EXTERNALLY-COOLED REACTOR

The design chosen to illustrate the heat-transfer characteristics of an ex-

Symbols

A_f = fuel-graphite interfacial area, ft²
A_c = cross-sectional area of core element, ft²
A_F = cross-section of flow in shell exchanger, ft²
A_g = average area of graphite for heat conduction, ft²
A_H = area for heat transfer based on tube OD, ft²
b = blanket saving, ft
B = a constant
C = specific heat, Btu/lb/° F
d = diameter of core, ft
D = inside diameter of tube or channel, ft
D_e = equivalent diameter = $4m$, ft
D_e' = equivalent diameter = $4m$, in.
D_o = outside diameter of tube, ft
h = heat-transfer coefficient, Btu/hr/ft²/° F
h_i = fuel-graphite interfacial heat-transfer coefficient, Btu/hr/ft²/° F
H = density of heat generation rate, Btu/hr/ft³
k = thermal conductivity, Btu/hr/ft/° F
K = a constant
l = distance above bottom of extrapolated core, ft
L = height of extrapolated core, ft
L_g = average thickness of graphite wall, ft
m = cross-section for flow/wetted perimeter, ft
N = number of core elements
q_f = heat-transfer rate from fuel surface, Btu/hr
q_{fl} = heat-transfer rate per foot of length, Btu/hr
Q = heat rate of reactor, Btu/hr
r = radius of fuel channel, ft
R = radial distance from center of extrapolated core, ft
R_e = radius of extrapolated core, ft
t = temperature of fuel at radius r, ° F
t_1 = temperature of fuel at center of channel, ° F
t_{1B} = bulk temperature of fuel, ° F
t_2 = temperature of fuel at outer boundary of channel, ° F
t_3 = temperature of graphite surface next to fuel, ° F
t_4 = temperature of graphite-cooled interface, ° F
t_5 = bulk temperature of coolant, ° F
v = linear velocity, ft/hr
θ = time, hrs
μ = viscosity, lb/hr/ft
ρ = density, lb/ft³
Subscripts: l = distance above bottom of extrapolated core, g = graphite, c = primary coolant stream or channel, f = fuel stream or channel

ternally cooled version of the LMFR represents a compromise in that a portion of the fission heat is transferred directly to the steam and the remainder through a secondary coolant.

A schematic diagram of the reactor, showing the core, blanket, and heat exchangers is shown on p. 12. The fuel mixture flows vertically through the reactor core and leaves at 520° C. A suitable moderator might consist of a bundle of vertical beryllium rods. After leaving the core, the heated fuel flows vertically through an unbaffled shell-and-tube heat exchanger located directly above the reactor. In this exchanger, heat is transferred to liquid sodium that becomes the heat source for steam superheating and reheating units, and fuel is cooled to 473° C.

Direct heat transfer from fuel to dry steam would require larger heat exchangers because of the low heat-transfer coefficient on the steam side. After being stripped of fission-product gases by sparged helium, the fuel stream divides and flows to two steam generators (one in each of two side loops) where it is cooled to 350° C. From the bottoms of the side loops, the fuel mixture is returned to the reactor core by centrifugal pumps.

The heat exchangers are suspended tube bundles. They can be lifted out of the reactor system without dumping the fuel and can be replaced with minimum difficulty. All welds are located in the gas space above the liquid metal.

TABLE 1—Design Conditions for Heat Exchangers for Externally Cooled LMFR

Heat rates, Mw	
Bismuth-sodium exchangers	82
Boilers	218
Total	300
Maximum allowable velocities, ft/sec	
Bismuth	10
Sodium	25
Temperatures, ° F	
Bismuth, core outlet	968
Bismuth, Na-exchanger outlet	884
Bismuth, boiler outlet	662
Sodium, Na-exchanger inlet	700
Sodium, Na-exchanger outlet	870
Saturated steam (1,045 psia)	550
Exchanger tube data	
Material	"Croloy" 5-Si
Thermal conductivity, Btu/hr/ft/° F	15
Thickness, in.	0.125
Spacing (triangular), in.	0.250

TABLE 2—Summary of Calculations for Externally Cooled LMFR

Conditions	*Tube sizes (ID, in.)*			
	0.400	*0.500*	*0.600*	*0.700*
Bismuth-sodium exchanger				
Bismuth coefficient, Btu/hr/° F/ft²	2,500	3,000	3,300	3,300
Sodium coefficient, Btu/hr/° F/ft²	16,000	13,000	13,000	12,000
Fraction of total resistance offered by tube wall	0.63	0.64	0.68	0.66
Max. temp. drop across tube wall, ° F	116	117	125	121
Max. thermal stress, lb/in.²	~16,000	~16,000	~16,000	~16,000
Number of tubes in parallel	2,600	1,662	1,257	1,120
Diameter, ft	4.0	3.6	3.4	3.5
Height, ft	7.5	9.3	10.4	10.6
Sodium velocity, ft/sec	25	25	23	19
Bismuth velocity, ft/sec	6.35	8.6	10.0	10.0
Sodium holdup, lb	910	1,120	1,370	1,690
Bismuth holdup, tons	15.3	13.9	13.5	13.6
Each boiler				
Bismuth coefficient, Btu/hr/° F/ft²	2,550	2,900	3,000	3,100
Steam coefficient, Btu/hr/° F/ft²	2,500	2,500	2,500	2,500
Fraction total resistance offered by tube wall	0.43	0.45	0.48	0.48
Max. temp. drop across tube wall, ° F	143	151	161	161
Max. thermal stress, lb/in.²	~20,000	~20,000	~20,000	~20,000
Number of tubes in parallel	1,265	895	740	621
Diameter, ft	2.8	2.6	2.6	2.6
Height, ft	15.5	16.8	17.3	18.0
Bismuth velocity, ft/sec	6.5	8.0	8.5	9.0
Bismuth holdup, tons	15.3	13.5	13.1	12.8

The tubes in the heat exchangers are U-shaped to minimize thermal stresses. This makes the fuel-sodium exchanger single-pass on the fuel side and double-pass on the sodium side and makes the boilers single-pass on the fuel side and double-pass on the steam side. The fuel flows outside the tubes. Fuel flow inside the tubes would reduce the fuel inventory, but it would mean more complicated construction, welded tube-sheets submerged in the fuel, and would increase the possibility of plugging. Pressure drops through the heat exchangers on the fuel side are minimized by having the fuel flow mostly parallel to the tubes.

The heat-exchanger tubes are single-wall. Thickness is determined by corrosion conditions rather than by strength requirements. Since the streams in both fuel-sodium and fuel-water exchangers are chemically incompatible, single-wall tubes might not be sufficiently reliable. Actual designs might require double-wall tubes with the fluid in the intervening space monitored for leaks. Advanced double-wall tube designs will have about the same over-all resistance to heat transfer as the single-wall tubes used here.

The reactor design considered here is an advanced one as far as present reactor technology is concerned, but it demonstrates the controlling factors and principles underlying design of heat-transfer components for an externally-cooled LMFR.

Design Conditions

Table 1 summarizes the assumed design conditions. Reactor total heat generation rate is 300 Mw; for any other heat rate, dependent heat-exchanger variables such as holdups, cross-sectional areas, and number of tubes are given by direct proportion. The maximum allowable velocities for bismuth and sodium have been set solely on the basis of erosion. Maximum bismuth temperature, 520° C (968° F), has been set by an arbitrary corrosion tolerance; the other temperatures were determined mainly by steam-cycle requirements.

Croloy 5-Si was chosen as tube material because of its superior corrosion resistance to bismuth. Tube-wall thickness was set at $\frac{1}{8}$ in. to insure against tubes failing from corrosion. Spacing between tubes was set at $\frac{1}{4}$ in. for all tube sizes. In standard practice, the

Calculating Core Sizes

Although this treatment refers to Type B core geometry, with minor variations it is applicable to all types.

For a constant and uniform heat generation in static fuel, the temperature-radius relationship for the fuel channel at steady conditions can be expressed by

$$\partial\,(r\,\partial t/\partial r)/r\partial r + (H/k) = 0 \qquad (2)$$

the solution for which, at fuel radius r_f, is

$$t_2 = t_1 - (r_f^2 H/4k) \qquad (3)$$

A heat balance gives

$$H = q_{ft}/\pi r^2 \qquad (4)$$

Combining this with Eq. 3

$$t_1 - t_2 = q_{ft}/4\pi k \qquad (5)$$

The over-all temperature drop from the center of the fuel channel to coolant stream ($t_1 - t_5$) is arbitrarily fixed. Thus,

$$t_2 - t_5 = t_1 - t_5 - q_{ft}/4\pi k \qquad (6)$$

The heat-transfer rate between the outer fuel surface and the coolant stream is

$$q_{ft} = \frac{t_2 - t_5}{(1/\pi h_i D_f) + (L_g/k_g A_g) + (1/\pi h_c D_c)} \qquad (7)$$

The fuel-graphite contact coefficient, h_i, is, as explained previously, fixed at a definite value. The coolant coefficient, h_c, is evaluated by the equation

$$h_c D_c/k_c = 4.9 + 0.018\,(D_c v_c \rho_c C_c/k_c)^{0.8} \qquad (1a)$$

After substituting Eqs. 6 and 1a into Eq. 7, an equation is obtained that gives q_{ft} as a function of v_c. Thus another equation of the type $q_{ft} = f(v_c)$ is necessary before q_{ft} can be evaluated.

The combined length of all the fuel elements is equal to Q/q_{ft} and also equal to $\pi d^3/4A_c$, giving

$$Q/q_{ft} = \pi d^3/4A_c \qquad (8)$$

Equating the sensible heat picked up by the coolant to the total heat rate of the reactor gives

$$N\,(\pi/4)\,D_c^2 v_c \rho_c C_c\ (\text{coolant temp. rise}) = Q \qquad (9)$$

$$N = \pi d^2/4A_c \qquad (10)$$

Combining Eqs. 8, 9, and 10 gives the second equation expressing q_{ft} as a function of v_c. The two simultaneous equations then can be solved to give values of q_{ft} and v_c from which the other dependent variables listed in Table 3 can be obtained readily.

tube spacing would be appreciably less and would vary with tube diameter; but the tubes are spaced widely to lessen the danger of plugging that is caused by buildup of intermetallic solids.

Bi-Na Heat Exchanger

Calculation results are summarized in Table 2. Of the four tube sizes investigated, the sodium velocity is limiting in the first two; bismuth velocity is limiting in the last two. Assuming that pumping power is not important, the velocities should be as high as possible to minimize resistance to heat transfer. Velocities of the two streams cannot be varied independently.

In the case of the 0.600-in. tube, the streams are either at or near their maximum allowable velocities. As tube size is increased: 1, the bismuth coefficient increases because its velocity increases (there is no change in equivalent diameter); 2, the sodium coefficient decreases (mainly because the diameter increases; the velocity effect is slight); 3, the fraction of total heat-transfer resistance offered by the wall is essentially constant at 65%; 4, maximum thermal stress in the tubes does not change significantly; 5, effect on bismuth holdup is slight; and 6, the number of tubes decreases considerably.

The chief reasons for the fact that the variation in bismuth holdup is slight is that the tube spacing and thickness are held constant. The tube spacing for tubes larger than 0.700 in. could in all probability not be held down to ¼ in. because of mechanical and construction requirements; which means that for such tubes the bismuth holdups would be considerably larger than those shown in Table 2. It thus appears that the optimum tube size would be around 0.600 in. to 0.700 in.

The calculated thermal stresses are rather high. At 900° F there are no figures available, but it is estimated that the stress required to produce 1% creep in 100,000 hr in Croloy 5-Si is about 12,000–14,000 lb/in.² (7). In view of the apparently conservative temperature drops across tube walls obtained from the theoretical elastic-stress equations compared to the temperature drops found in practice, it is concluded that the thermal stresses in Table 2 are practical.

Boilers

Boiler calculations were simplified by assuming: 1, boiler water temperature is independent of height and is the saturation temperature corresponding to the steam-drum pressure; and 2, steam-side (forced circulation) heat-transfer coefficient is 2,500 Btu/hr/ft²/° F and is independent of tube size.

To minimize bismuth inventory, there should be only a very small isothermal flow in the heat-transfer loops. This means that boiler length should be roughly equal to the height of the reactor plus the length of the bismuth-sodium heat exchanger.

As in the bismuth-sodium exchanger, the effect of tube size on bismuth holdup is small. Optimum tube size is also around 0.600–0.700 in.; and the thermal stresses are high but tolerable. The 0.700-in. tube size requires only half as many tubes as the 0.400-in. size, making the number of tubes a big factor in determining optimum tube size. Probability of tube failure decreases when fewer tubes are used.

For transfer of 300 Mw of heat, total bismuth holdup in the heat-exchangers is approximately 40 tons.

INTERNALLY-COOLED REACTOR

As shown in Fig. 2 on p. 12, the core is essentially a large right-cylindrical block of graphite, in which the liquid-metal fuel is contained in a large number of interconnected vertical channels. The primary coolant flows in a separate

set of parallel channels. Heat is transferred from fuel to coolant through graphite walls. The graphite serves to: 1, separate fuel and coolant; 2, transfer heat from fuel to coolant; and 3, slow fission neutrons to thermal energies.

The fuel in the core may remain static or it may be slowly circulated. The primary coolant, after rising vertically through the core, splits into eight equal streams, each of which is pumped to a secondary heat exchanger. These eight heat exchangers, two of which are standbys, are distributed uniformly outside the blanket, which in turn surrounds the core. In the exchangers, the primary coolant is cooled from 520° to 350° C by flowing down single-pass,

Core Temperatures

Since heat-generation intensity is a J_0 Bessel function of the radius, the heat flux from the core's top face (the heat transported by the primary coolant), at any value of the radius, is

$$(dq_t/dA) = BJ_0[2.405\ R/R_0] \tag{11}$$

or,

$$dq_t = 2\pi BJ_0[2.405\ R/R_0]\ RdR \tag{12}$$

which, upon integration, gives

$$q_t = (\pi BRR_0J_1/1.202)[2.405\ R/R_0] \tag{13}$$

Since R_0 is fixed (7 ft. in this case) and q_t is known for the whole core, the constant B can be evaluated.

The total heat rate in any one fuel channel is

$$[q_f]_{l=L-b} = A_cBJ_0[2.405\ R/R_0] \tag{14}$$

The heat flux from the surface of a fuel channel is a sine function of the height. Thus,

$$\frac{dq_f}{dA_f} = \frac{dq_f}{2\pi r_f dl} = K \sin\frac{\pi l}{L} \tag{15}$$

therefore

$$dq_f = K2\pi r_f \sin\frac{\pi l}{L}\,dl \tag{16}$$

Integrating, we get

$$[q_f]_{l=L-b} = -2\pi r_f K\left[\frac{\cos\frac{\pi l}{L}}{\frac{\pi}{L}}\right]_{l=b}^{l=L-b} \tag{17}$$

By combining Eqs. 14 and 17, the constant K can be determined. At any height l, we have

$$[q_f]_l = -2Lr_fK\left[\cos\frac{\pi l}{L} - \cos\frac{\pi b}{L}\right] \tag{17a}$$

For static fuel, the proportionality equation

$$\frac{[q_f]_l}{[q_f]_{l=L-b}} = \frac{(t_5)_l - t_5(\text{inlet})}{t_5(\text{outlet}) - t_5(\text{inlet})} \tag{18}$$

will give the coolant temperature, t_5, at any given value of l. Knowing the heat flux $(\partial q_f/\partial A_f)_l$ as a function of l, the surface temperature of the fuel, t_2, can be obtained for any value of l by the equation

$$\left(\frac{\partial q_f}{\partial A_f}\right)_l \pi D_f = \frac{(t_2)_l - (t_5)_l}{\frac{1}{\pi h_cD_f} + \frac{L_g}{k_gA_g} + \frac{1}{\pi h_cD_c}} \tag{19}$$

Knowing $(\partial q_f/\partial A_f)$, t_2, t_5, and the three resistances to heat transfer as functions of l, it is easy to get the intermediate temperatures, t_3 and t_4, for different values of l. The temperature in the center of the fuel channel, t_1, can be obtained from the equation

$$\left(\frac{\partial q_f}{\partial A_f}\right)_l D_f = 4k_f(t_1 - t_2) \tag{20}$$

which is analogous to Eq. 5. The valid assumptions that axial heat conduction in the fuel and coolant and linear heat conduction in the graphite are negligible were implicit in the derivations.

Forced circulation. For the case of forced circulation of the fuel stream, if changes in the sensible heat content of the fuel (as it rises through the core) can be neglected, we have the equation

$$\left(\frac{\partial q_f}{\partial A_f}\right)_l \pi D_f = \frac{(t_{1B})_l - (t_5)_l}{\frac{1}{\pi h_fD_f} + \frac{L_g}{k_gA_g} + \frac{1}{\pi h_cD_c}} \tag{21}$$

which, when combined with Eq. 15, makes it possible to calculate t_5 for any value of l.

If the sensible heat effect were not negligible, we could consider a volume of fuel having a surface area of 1 ft² rising through the core. For such a volume:

$$\begin{aligned}(\text{net heat gain}) = (\text{heat generated}) + (\text{heat received by}\\ \text{axial conduction}) - (\text{heat lost by axial}\\ \text{conduction}) - (\text{heat lost by radial transfer})\end{aligned} \tag{22}$$

Heat exchange by axial conduction in all cases is negligibly small.

$$\text{net heat gain} = (D_f\rho_fC_fdt_{1B}/4) \tag{23}$$

$$\text{heat generated} = K \sin(\pi v_f\theta/L)d\theta \tag{24}$$

and,

$$\text{heat lost by radial transfer} = \frac{(t_{1B} - t_5)d\theta}{\frac{1}{h_f} + \frac{L_g}{k_g(A_g/A_f)} + \frac{1}{h_c(D_c/D_f)}} \tag{25}$$

The coolant temperature, t_5, can be expressed as a function of θ by an equation similar to Eq. 18. Thus, on substitution of these four expressions into Eq. 22 a differential equation is obtained that gives t_{1B} as a function of θ. The solution of this equation is somewhat unwieldy. Experience has shown that the slightly greater accuracy obtained never justified the extra work involved. For this reason, the solution of Eq. 22 has been omitted here.

transferring its heat to a secondary coolant of either sodium or lead. From the secondary heat exchangers, the primary coolant returns to the bottom of the reactor to repeat the cycle. The secondary coolant is the heat source for the steam-generating equipment.

The primary coolant plays another important role. As a liquid metal mixture containing fertile material, it is also the breeding stream. Thus, at the bottom of the reactor, a small portion of the returning coolant flows up through the blanket to remove the relatively small amount of heat generated therein. It is obvious that breeding is accomplished both inside and outside the reactor core. It is desirable to do internal breeding with internal cooling to minimize the relative loss of neutrons by bismuth capture.

Thus, this reactor is a complicated machine in which fission, breeding, neutron moderation, parasitic neutron capture, flow of materials, and heat transfer are occurring simultaneously. These processes are interdependent and each must proceed at a definite rate to maintain satisfactory reactor operation. Thus, size, geometry, and general reactor design must meet the requirements of all these processes. This always involves compromise because a beneficial change in a particular independent variable is usually detrimental to another variable.

Oddly enough, the heat-transfer process, and not nuclear considerations, usually has the greatest influence on the size and design of an internally cooled reactor.

This design of internally cooled LMFR, like the externally cooled version described earlier, is admittedly advanced as far as present technology is concerned; but it is believed to be within the realm of possibility a few years hence. Moreover, as far as heat transfer is concerned, this design also minimizes fuel inventory and plant investment.

Core Designs

In comparing calculated heat-transfer capacities for different core designs, it was assumed that: 1, natural convection in fuel channels would not appreciably affect radial heat transfer, because of the high thermal conductivity of the fuel mixture; 2, physical properties of fuel mixture and primary coolant are same as those of pure bismuth; 3, maximum allowable linear velocity for bismuth is 10 ft/sec; 4, core shape is that of right cylinder with height equal to diameter; 5, core is a solid graphite structure with separate fuel and coolant channels; 6, heat generation rate is uniform throughout the core; 7, contact coefficient of heat transfer between nonflowing fuel and graphite is 10,000 Btu/hr/ft²/° F (a rough estimate); and 8, under the conditions of temperature and neutron flux existing in the core, the thermal conductivity of graphite is 30 Btu/hr/ft/° F and constant throughout the core.

Since the primary coolant is also the breeding stream and since the container walls separating the fuel from the coolant serve as moderator, the core must provide certain relative volumes of graphite, fuel, and coolant. These volumes must be so arranged that the core does not become excessively large to provide the necessary heat transfer capacity.

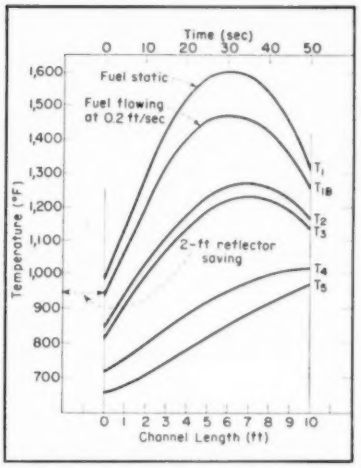

FIG. 2. Temperature variations along Type-B element at center of 10-ft core of internally cooled LMFR

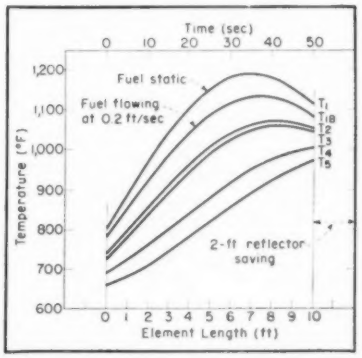

FIG. 3. Temperature variations along Type-B element at periphery of 10-ft core of internally cooled LMFR

The three core elements shown in Fig. 1 were chosen for comparison. The total heat load is 500 Mw; maximum feed temperature, 800° C; and upper and lower coolant temperatures were set at 520 and 350° C, respectively. The assumption of uniform heat generation renders the results somewhat inaccurate on an absolute basis but does not effect them relatively. For more accurate designs, variation in heat-generation rate with core height and core radius must be considered. This was done for Type B and will be treated in the following section.

Comparison of the four cases in Table 3 shows that core size and fuel and coolant holdups decrease progressively across the table. This is principally due to four effects: increase in fuel-coolant volume, decrease in fuel-channel size, imposition of turbulent flow on fuel stream, and improvement in geometrical design. The choice of design would, of course, be influenced by the relative ease of fabrication. For the designs presented here, little consideration has been given to the question of fabrication; and the designs have not been fully optimized. They are, however, appropriate for the type of reactor under consideration.

Temperature Distribution

The actual temperature distribution in the core must be calculated considering variations in heat-generation rate with height and radius. This rate, paralleling the neutron flux, can be closely approximated by a simple sine function of the height and a zero-order Bessel function of the radius. It is apparent from Fig. 2 on page 12 that the neutron flux will extend beyond the core into the surrounding blanket to a distance of about 2 or 3 ft; depending on the blanket composition and thickness; which means that, in effect, the heat generation density in the core is "flattened." For design heat-transfer purposes, this flattening can be simulated by increasing core size, permitting the heat generation rate to reach zero at the extended boundaries, and keeping the total heat-generation rate inside the actual-size core equal to the design figure.

Center element. Figure 2 shows how temperature varies along the central element of a 10 × 10-ft core with Type-B elements. The curves were calculated using the assumptions stated previously. Coolant flow

TABLE 3—Comparison of Core Designs for Internally Cooled LMFR

Variables	*Type of fuel element geometry*			
	A	*B*	*C*	*C*
Independent				
Volume ratio, fuel/coolant	0.100	0.200	0.200	0.200
Volume ratio, graphite/coolant	1.45	1.46	2.28	2.28
Cross-sectional area of each fuel channel, in.²	0.0840	0.1104	0.0490	0.0490
Reynolds number of fuel	0	0	0	6,000
Dependent				
Core diameter and height, ft	11.6	9.45	8.25	7.73
Number of fuel channels	7,070	6,900	9,020	7,930
Fuel velocity, ft/sec	0	0	0	0.273
Primary coolant velocity, ft/sec	1.71	2.63	4.57	5.20
Primary coolant residence time, sec	6.78	3.58	1.80	1.48
Total temp. gradient across radius of fuel channel, ° F	184	232	202	—
Temp. drop across fuel film, ° F	—	—	—	185
Temp. drop across fuel-graphite interface, ° F	24	27	35	—
Avg. temp. drop across graphite, ° F	103	164	200	243
Temp. drop across primary coolant film, ° F	193	81	67	76
Total fuel weight (as Bi), tons	14.1	14.8	7.48	6.17
Total primary-coolant weight (as Bi), tons	156	76.7	38.8	32.0

through the core is regulated by orifices so that temperature rise through the core is the same for the coolant in all channels (350° to 520° C). This mitigates thermal-stress problems. Temperature distribution is flattened to the extent that a 2-ft blanket saving is assumed; i.e., the heat generation rate was set at zero on the surfaces of a 14 × 14-ft cylinder, while keeping the total generation rate within the central 10 × 10-ft core equal to 500-Mw.

The central element is the hottest and has the steepest temperature gradients. From such a plot as Fig. 2, the major resistances to heat transfer can be located quickly. In addition, Fig. 2 shows the highest temperature attained by the fuel, the temperature range of the graphite, and the greatest temperature drop across the graphite wall. All of these are important.

The fuel, when nonflowing, reaches a maximum temperature of about 1,620° F, which under certain circumstances may be too high for fuel stability. This temperature can be reduced most easily by increasing the core size or by imparting turbulent flow to the fuel, or both.

By flowing the fuel at a linear velocity of 0.2 ft/sec, which is sufficient to give considerable turbulence, the maximum fuel temperature was reduced up to 150° F. Under these conditions, the maximum temperature drop across the graphite (which occurs about 6 ft from the core bottom) is safely below the permissible maximum from a thermal-stress standpoint.

Edge element. Figure 3 shows how temperature varies along a fuel element at the core edge, where heat-generation density is least. In this case, the top fuel temperature, even for nonflow conditions, is only 1,190° F. This is more than 400° below that in the central element. The coldest graphite in the central and peripheral elements are at 710 and 690° F, respectively. These temperatures are important from the standpoint of stored energy in, and neutron damage to, the graphite.

When considering types of curves shown in Figs. 2 and 3, it must be remembered that the temperature patterns are affected by the amount of reflector saving assumed in their calculation. The 2-ft saving assumed in the present case is realistic. Had the curves in Fig. 2 been based on a 1-ft blanket, the central element would have given (for the turbulent-fuel case) a maximum fuel temperature of 1,830° as against 1,470° with the 2-ft blanket. A peripheral element under these conditions would show minimum and maximum temperatures of 720° and 1,110°, compared with 800° and 1,190° for the 2-ft case.

For slurry fuel mixtures, the lowest fuel temperature existing in the core determines the maximum slurry concentration, which can be an important factor.

Heat Exchangers

The secondary heat exchangers are of conventional unbaffled shell-and-tube design. Primary and secondary coolants flow single-pass outside and inside tubes, respectively. To reduce holdup of primary coolant in the exchangers, this more valuable stream should flow inside the tubes; but the increased danger of plugging from precipitate buildup and the more difficult design problems make this method less attractive.

With primary coolant outside the tubes, the heat exchangers can be suspended in long, vertical, cylindrical graphite wells. This exposes a minimum of welds to the primary coolant and permits convenient replacement of tube bundles.

Counter-current flow of primary and secondary coolants is achieved by passing the secondary coolant down through the center to the bottom of the exchanger and then distributing it to the individual tubes. It then flows vertically to the top of the exchanger and on to the steam-generating units. The central down-pipe for the secondary coolant can be eliminated by making the heat-exchanger tubes double-pass on the sodium side. This is not feasible in this case because the exit temperatures of both coolants, being close together, would result in considerably larger heat exchangers.

The design also should have a low depreciation rate and be safe and reliable.

Design variables for the secondary heat exchangers are: 1, total heat rate; 2, number of exchangers in parallel; 3, secondary coolant; 4, tube material; 5, tube diameter; 6, tube thickness; 7, tube spacing; 8, inlet and outlet coolant temperatures; 9, length of heat exchangers; 10, velocity of primary coolant; 11, velocity of secondary coolant; 12, diameter of each heat exchanger; 13, number of tubes in each heat exchanger. The first nine are independent variables; the latter

four, 10–13, are dependent variables.

The holdup of primary coolant in the heat exchangers depends, among other things, on its linear velocity therein. Since the total flow of primary coolant is fixed, the exchangers should be as narrow and long as possible to minimize its holdup. The maximum length permissible in this case is 18 ft. Thus, exchanger length is considered an independent variable. This makes the velocities of the two coolants dependent variables. If, by this procedure, the linear velocity of either coolant is greater than is allowable, the exchangers must be shortened until the velocity of either coolant does not exceed its allowable maximum.

In Table 4, six exchanger designs are described. In each case, the reactor is producing 500 Mw of heat; the primary coolant is cooled from 968° to 662° F; the secondary coolant is heated from 572° to 879° F; the exchanger tubes are spaced 0.250 in. apart and have walls 0.125 in. thick; and the tube material is Croloy 5-Si, which has a thermal conductivity of 15 Btu/hr/ft/° F. Three examples (*a*, *b*, and *c*) use sodium as secondary coolant, and three (*d*, *e*, and *f*) use lead (a lead-bismuth eutectic would give results similar to those for lead). Besides the two coolants, the inside diameter of the tubes is the chief independent variable.

TABLE 4—Heat-Exchanger Designs for Internally Cooled LMFR

Variable	*Case*					
	a	*b*	*c*	*d*	*e*	*f*
Secondary coolant	Na	Na	Na	Pb	Pb	Pb
Tube ID, in.	0.250	0.500	0.750	0.250	0.250	0.500
Total no. of tubes	13,300	8,500	6,450	15,500	18,700	11,270
Bi velocity betw. tubes, ft/sec	2.62	2.79	2.77	2.24	1.86	2.10
Coolant velocity in tubes, ft/sec	20.7	8.10	4.74	12.1	10.00	4.15
Bi ht. tr. coeff., Btu/hr/ft²/° F	1,590	1,654	1,653	1,493	1,384	1,474
Coolant ht. tr. coeff., Btu/hr/ft²/° F	21,815	10,350	6,550	6,090	5,550	2,552
Over-all ht. tr. coeff., Btu/hr/ft²/° F	607	634	626	521	498	478
No. of exchangers	6	6	6	6	6	6
Length of heat exchangers, ft	18	18	18	18	15.6	18
Diameter of heat exchangers, ft	3.25	3.45	3.72	3.54	3.85	3.97
Bi holdup, tons	148	139	142	172	180	184
Total holdup of coolant, tons	4.4	7.8	9.6	68	65	128
Max. vel. of secondary coolant, ft/sec	20.7	20	20	12.08	10	10

For the sodium cases, the ID's are 0.250 in., 0.500 in., and 0.750 in.; these all give the same equivalent diameter on the bismuth side. This is why the heat-transfer coefficients for the bismuth do not vary significantly with tube diameter.

Bismuth holdup does not vary greatly with tube size. As tube size increases, the required heat-transfer area also increases due to the decrease in the sodium coefficient. But, as tube size increases, the relative space between tubes decreases. This compensating effect accounts for the relative constancy of the bismuth holdup.

The sodium holdup, on the other hand, increases greatly with tube size; but since it is cheap and small in quantity, this is no great disadvantage. Engineering considerations and ease of fabrication would influence choice of a tube size around 0.750 in. Tube sizes larger than this would mean appreciably larger bismuth holdups because tube spacing could not be held to 0.25 in.

The same general situation applies to the three designs in which lead is the secondary coolant, except that the bismuth holdup in the exchangers increases with tube size. As tube size increases, the lead film coefficient decreases faster than the sodium coefficient did. In case *d*, when length is fixed at 18 ft, the velocity of the lead in the tubes exceeds the set maximum of 10 ft/sec by about 20%. In case *e*, lead velocity is held at 10 ft/sec and length comes out to be 15.6 ft. Again, the effect of tube size on bismuth holdup is not great, but optimum tube size would probably be around ¾ in. ID.

Table 2 shows that sodium as secondary coolant gives bismuth holdups considerably below those for lead; also, that lead holdups are several fold greater than those for sodium. Thus, from the holdup standpoint, sodium shows a real advantage over lead. On the other hand, from the standpoint of chemical reactivity, lead has the advantage over sodium, since it will not react exothermally with bismuth or water.

With sodium, safety and reliability requirements would probably dictate use of double-wall tubes with an intermediate fluid. This would allow the detection of a tube rupture before a leak into the sodium could occur. The damaged unit would then be isolated from the system and replaced. Improved double-wall tubes should give heat-transfer coefficients similar to those in Table 4 for single-wall tubes.

Aside from its lack of chemical reactivity, lead has another advantage over sodium. It does not become as radioactive, thus, its piping system requires less shielding. Lead entails higher pumping power, higher cost, greater corrosion problems, and poorer heat-transfer characteristics. In the final analysis, the choice of secondary coolant can be determined only by an economic balance, with consideration of plant safety and reliability.

* * *

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BIBLIOGRAPHY

1. R. N. Lyon, *Trans. Am. Inst. Chem. Engrs.* **47,** 75 (1951)
2. R. A. Tidball. Performance of small liquid metal heat exchangers (Heat Transfer Symposium, American Institute of Chemical Engineers, Dec. 5, 1951)
3. D. A. Donohue, *Ind. Eng. Chem.* **41,** 2499 (1949)
4. R. D. Brooks, A. L. Rosenblatt, *Mech. Eng.* **75,** 363 (1953)
5. C. F. Bonilla, S. J. Wong, NYO-3091 (1952)
6. R. N. Lyon, ed., "Liquid Metal Handbook" (U. S. Government Printing Office, Washington, D. C., 1952)
7. Technical Bulletin 6F (Babcock and Wilcox Co., 1953)

LMFR PART VII

Behavior of steels in contact with uranium-bismuth solutions, effects of graphite and steels on fuel stability, and effects of additives on mass transfer are shown here

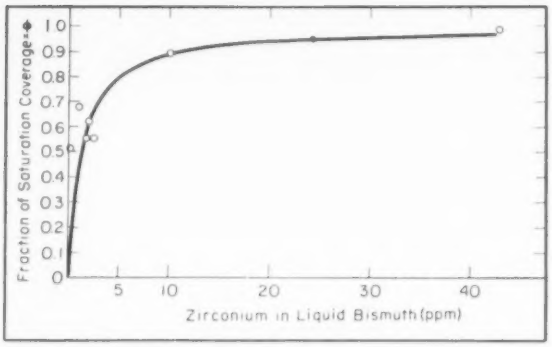

FIG. 1 Adsorption of Zr on Fe crucible from liquid Bi at 400° C

Finding a Container Material for the Uranium-Bismuth Fuel System

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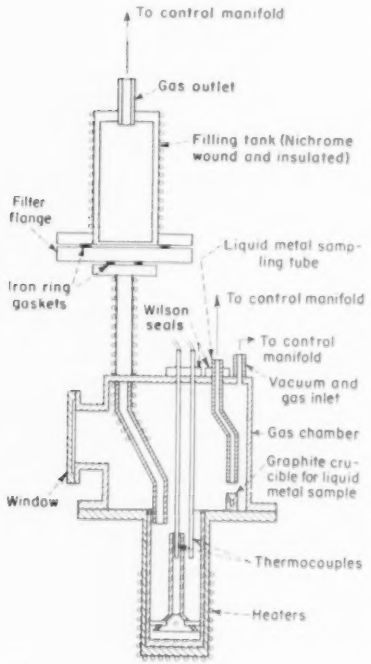


CONTAINER MATERIALS have been studied to learn: 1, Will the material be corroded by the liquid fuel? 2, How does the temperature gradient affect corrosion? (i.e., is mass transfer a serious problem?) 3, How do the corrosion products affect uranium's solubility in bismuth? 4, Does the material have a high-enough mechanical strength and creep resistance at the operating temperatures?

After a literature survey, the iron-chromium alloys were selected for particular study. This selection has not precluded the investigation of other materials; studies on Mo, Cb, Ta, and other alloys have not been completed.

Static Corrosion Tests

Static corrosion tests have been carried out on iron-chromium alloys. Of the alloys tested, the 2¼%-Cr:1%-Mo and the 5%-Cr:1½%-Si steels were most corrosion resistant.

Since even these two steels showed a penetration of 5 mils/yr, which is excessive, small amounts of other metals were added to the bismuth media in the hope that these might inhibit corrosion; Mg and Zr show the most promise.

Convection Loop Tests

Dynamic testing of the materials in thermal convection loops has started. In all dynamic tests, the bismuth media and the inner wall of the loop are treated with purified hydrogen for 4 hr at 550° C. The bismuth is filtered into the loop.

Three loops (2¼-Cr:1-Mo) of ½-in.-IPS containing uranium in bismuth were operated until Fe-Cr deposited in the cold leg and stopped circulation. The time required to plug the three loops was 383, 300, and 260 hr. The maximum penetration in the hot leg of the 300-hr loop was 2 mils.

A loop (5-Cr:1½-Si) of large bore

QUALITATIVE MASS-TRANSFER DATA: POT FASTER THAN LOOPS

FIG. 2. Convection-pot apparatus consists of filling tank, gas chamber, convection pot (graphite), gas system, and devices for inserting and removing samples. Test samples are cylinders 0.280-in. OD × 0.010-in. wall × 0.750-in. long, held on graphite tubes. Filling tank is loaded with Bi; radioactive test sample is placed above hottest region in graphite pot (475° C); nonradioactive sample is placed above pot's coldest region (450° C); purified H_2 is bubbled through Bi in melt pot; pressurizing melt pot forces liquid Bi into graphite pot; Bi samples can be removed with pipette; at end of run, corrosion samples are removed from liquid and cooled; apparatus is dismantled and Bi is analyzed for dissolved elements; gamma scintillation spectrometer measures "cold" sample for transferred radioactivity

Corrosion of Croloy 5-Si and High-Purity Iron in a "Hot-Cold" Bismuth Loop

Material	Test period (hr)	Liquid metal analysis at start and end of test (ppm) U Start	U End	Zr Start	Zr End	Mg Start	Mg End	Sample shape; preparation	Average penetration (10^{-3} in.)	Remarks
Croloy 5-Si	1,000	480	450	300	240	400	350	Square; surface ground	3	Sample wetted;* local attack
Croloy 5-Si	2,000	450	410	240	210	350	210	Square; surface ground	1	Sample wetted; local attack
Croloy 5-Si	3,000	480	410	300	210	400	210	Square; surface ground	—	Sample wetted, mechanical surface poor, penetration questionable
Croloy 5-Si	1,000	410	440	210	275	210	420	Square; surface ground	3	Sample wetted, local attack
Hi-purity Fe	1,000	410	440	210	275	210	420	Square; surface ground	0.8	Partially wetted, uniform attack
Croloy 5-Si	1,000	440	440	275	250	420	310	Round; centerless ground, as received	0.0	Partially wetted, looks good, no corrosion
Croloy 5-Si	1,000	440	440	275	250	420	310	Round; centerless ground, annealed	0.0	Partially wetted, looks good, no corrosion
Croloy 5-Si	1,000	440	440	275	250	420	310	Round; centerless ground, electro-polished	0.0	No wetting, looks good, no corrosion

* "Wetted" means that bismuth is adhering to sample removed from harp.

(1.7-in. ID) containing 440 ppm U in Bi was run and showed a steady loss of uranium from the solution during operation. After 2,441 hrs, the difference in temperature between hot and cold legs started to increase, indicating plug formation. The loop was shut down. Metallographic examination revealed that the plug was in the coldest section. X-ray and spectrographic analysis identified the plug as iron-chromium alloy. Maximum penetration in the hot leg was 20 mils.

A loop (2¼-Cr:1-Mo) of large bore (1.3-in. ID) containing 500 ppm U in Bi was operated until the uranium concentration dropped off to 90 ppm, at which time 400 ppm magnesium and 250 ppm zirconium were added. The uranium concentration then rose to 330 ppm, where it stabilized. Additional uranium was added to bring the concentration up to 1,000 ppm. Effect of operating time on the concentration of U, Zr, and Mg is being studied.

A loop (2¼-Cr:1-Mo) of large bore (1.3-in. ID) containing 500 ppm U and 100 ppm Mg was run for 750 hours. There was a slight uranium loss. Magnesium and zirconium were added to bring the concentration of each up to 200 and 100 ppm, respectively. These additions did not change the concentration of uranium. The concentrations of Mg and Zr were then increased to 350 and 250 ppm, respectively. After allowing time for the concentrations of the additions to stabilize, graphite was inserted in the "hot" leg to determine the effect of graphite on the concentration of zirconium, magnesium, and uranium. Analysis after 2 hr operation showed that 70 ppm of uranium had been lost. No further loss of uranium was detected after operating 1,000 hr.

A loop (2¼-Cr:1-Mo) of large bore (1.3-in. ID) containing 1,000 ppm U, 250 ppm Mg, and 80 ppm Zr ran for 6,800 hr, at which time it was shut down because of mechanical difficulties. Microscopic examination of the sectioned loop revealed some precipitation of an iron-chromium alloy on the wall of the cold leg but no portion of the loop was plugged. The U concentration remained constant while Zr and Mg dropped off. Maximum penetration in the hot leg was 3 mils.

Another loop (5-Cr:1½-Si) of large bore (1.7-in. ID) containing 450 ppm U, 350 ppm Mg, and 250 ppm Zr has operated for 9,000 hr with no signs of plugging. The first 1,050 hr were devoted to studying the concentrations of uranium, zirconium, and magnesium with time with the concentrations of all three remaining constant. Dynamic samples of various materials were placed in both the "hot" and "cold" legs of this loop. The data obtained on these samples is shown in the table.

Two ½-in. IPS loops (2¼-Cr:1-Mo) have operated for 3,000 and 2,500 hr, respectively, without any sign of plugging. These loops contain 760 ppm U, 250 ppm Mg, 250 ppm Zr; and 880 ppm U, 1,000 ppm Mg, 1,000 ppm of Zr, respectively.

It is important to note that loops that did not originally contain magnesium and zirconium showed a loss of uranium and plugged in a short time. The penetration of the wall in the hot leg of the loop without inhibitors was 20 mils in 2,000 hr, whereas the penetration in the hot leg of a loop operated for 6,800 hr with inhibitors was only 3 mils.

Inhibitor Studies

Since engineering experiments demonstrated that adding zirconium and magnesium to uranium-bismuth solutions reduces mass transfer, the mechanism was investigated using radioactive tracers.

Molten bismuth containing 500–1,000 ppm Mg and variable amounts of radioactive Zr^{95} was filtered through a type-410 stainless-steel filter into a clean, freshly pickled, pure-iron crucible. The system was equilibrated under vacuum for 1 hr at 400° C. After the melt was solidified, the bismuth and crucible were separated

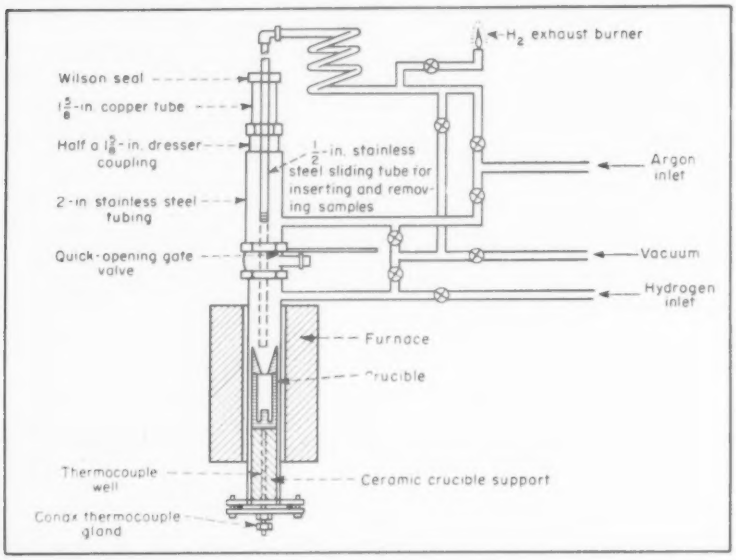


FIG. 3. Apparatus consists of crucible (material being tested, or "inert" Mo or C), furnace, gas system, and devices for inserting and removing samples. Bismuth (450 gm) is placed in a 6-in.-long $1\frac{1}{4}$-in.-diam Croloy pipe whose lower end is sealed by a chromium stainless steel filter; top of pipe is attached to sliding tube and is lowered into 600° C furnace; for 1 hr purified H_2 passes into apparatus, through filter and liquid Bi and is burned; system is evacuated; purified-gas pressure applied to liquid metal forces it through filter and into crucible; empty Croloy pipe is removed; crucible and purified Bi are held in contact with test material overnight at 600° C before test starts

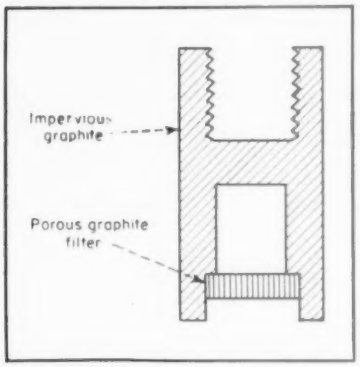


FIG. 4. Sampler attached to sliding tube periodically removes specimens for analysis. Filter is preheated above liquid level for about 1 hr; sampler is dipped into bath; 20-psi inert gas forces liquid into cup; sample cooled, removed; crucible temperature is adjusted. Complete temperature-solubility curve is obtained in 2 or 3 days

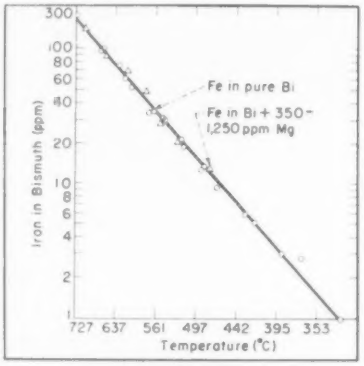


FIG. 5. Iron's solubility in bismuth varies from 3 ppm at 390° C to 175 ppm at 725° C. Approximately 500 ppm magnesium additive in bismuth does not affect iron's solubility. Effect of zirconium and chromium additives on solubility is being investigated. Knowledge of solubility is essential to understanding mass transfer and corrosion

under hot mineral oil and each surface was analyzed for radioactivity.

Preliminary results indicate that zirconium chemisorbs on the iron's surface. A Langmuir-type adsorption isotherm was obtained as shown in Fig. 1. The smooth curve is that of the Langmuir equation calculated from the experimental data for zirconium concentration between 1.5 and 10 ppm; the adsorbed zirconium found at 43 ppm is seen to be close to this curve. From this curve, the adsorption energy was calculated to be 16,000 calories per gram atom of Zr; this is clearly in the energy range of an adsorption process.

A monolayer of adsorbed zirconium appears to be formed at a concentration of 50 ppm Zr. It has been reported that 25 ppm titanium in bismuth are required to minimize mass transfer in circulating bismuth systems. If the actual surface area of the pickled iron crucible is assumed to be five times the measured area, there would be approximately one adsorbed zirconium atom to every eight iron atoms on the crucible surface at saturation coverage.

These experiments seem to substantiate the belief that an adsorbed layer forms. By retarding diffusion of iron into the stream, such a layer might inhibit corrosion in the hot region. In the cold leg such a layer might prevent precipitation of the dissolved constituents. A higher degree of supersaturation would result with a possible volume precipitation. This solid then could be transferred into the hot region where it would redissolve in a preference to dissolution of the wall. Surface-reaction studies are in progress.

Convection Pot Tests

With the convection pot (Fig. 2), it is possible to: 1, rapidly measure mass transfer (by using radioisotopes); 2, circulate the liquid by convection; 3, observe specimens during a run; 4, sample the liquid at any time; and 5, introduce highly-purified liquids.

Four runs have been made. The test samples were pure iron. Before being inserted in the apparatus, the irradiated iron samples had an activity of 25 mr/hr at 5 in. Calculated mass-transfer rates of 0.0050 mg/hr and 0.0062 mg/hr were obtained in the two runs in bismuth. No transferred activity could be detected on the "cold" samples in the two runs in which 1,000 ppm uranium, 300 ppm magnesium, and 350 ppm zirconium were present in the bismuth. In the latter two runs, the iron samples had no bismuth adhering to them at the end of the run.

Since uniform wetting is a requisite for obtaining comparable results, this phenomenon has been studied and all future runs will be made on samples wetted prior to insertion.

Conclusion

A continuation and extension of this work should yield a solution to the container-material problem.

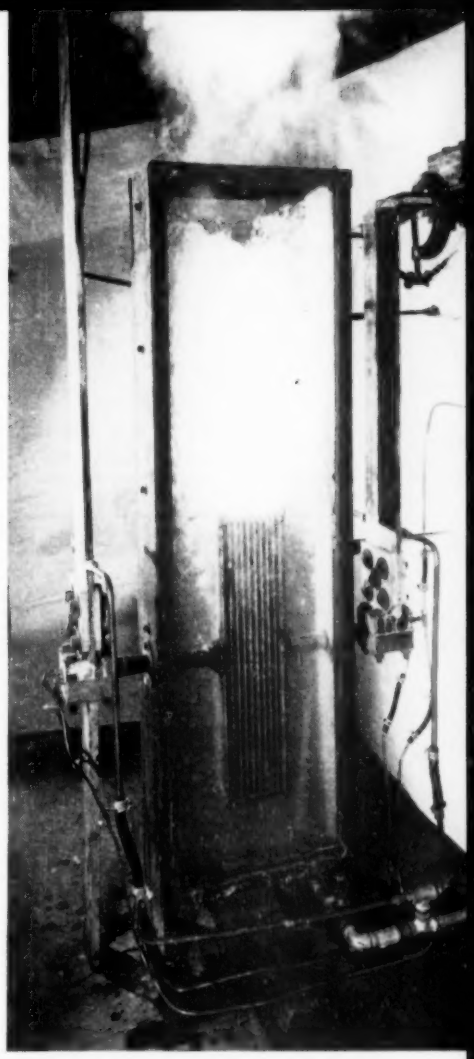
* * *

The authors wish to acknowledge the valuable assistance of R. Stoenner and M. Slavin for the chemical analyses performed in support of this work.

Boiling Reactors:

Direct Steam Generation for Power

Experiments prove that boiling, originally thought to make reactors unstable, can provide self-regulation of a reactor and at the same time directly transfer reactor heat to steam capable of driving a power-generating turbine. Elimination of secondary coolant system provides economic and technical advantages



FIRST PROOF that usable amounts of power could be obtained through use of boiling principle was obtained with this laboratory apparatus. Electrically heated plates produced steam velocities much greater than predicted theoretically

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Lemont, Illinois

By the year 2,000, a nuclear power plant might conceivably consist of a chain-reacting core and two wires, through which the plant's output could be delivered as high-voltage electricity. Pending development of certain technical features, more conventional methods must be used to extract useful electric energy from fission.

At the present time, reactor heat is used to generate steam, which is expanded in a turbine to produce power. Until recently an intermediate reactor coolant seemed necessary; now, direct steam generation by boiling water within the reactor has been proved.

Another current limitation on nuclear power is the requirement that a reactor be located within an exclusion area of approximately one acre for each electric kilowatt of reactor output (*1*). This formula would be inapplicable to a reactor that would "fail safe" so that mismanagement during operation could not possibly lead to serious failure. It is believed that the boiling principle can be applied to provide inherent reactor safety.

Direct Boiling Cycle

Direct generation of steam within the reactor vessel is the most straightforward way to use reactor heat. But only recently have direct-cycle boiling reactors received the attention they deserve. Last summer this laboratory tested an experimental reactor using this principle; an abridged description has been released by AEC (*2*).

By cooling power reactors with boiling water, cumbersome and expensive components of the reactor steam plant can be eliminated. Since steam generated within a boiling reactor is fed directly into a turbine, heat exchangers are not required. Ample coolant circulation through the fuel can frequently be obtained from the natural buoyancy of the steam bubbles, so that circulating pumps may not be required. Only reactor feed pumps are needed, and, since these units are about one-twentieth the capacity of the usual coolant circulating pumps, the pumping requirements of natural-circulation

* Present Address: General Electric Co., Schenectady, New York.

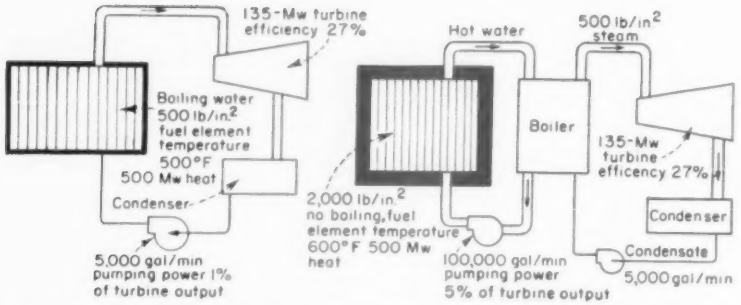


FIG. 1. Comparison of conventional reactor and heat exchanger with boiling reactor supplying same turbine steam requirements

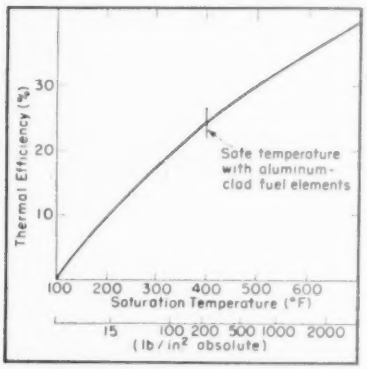


FIG. 2. Temperature and pressure limitations on thermal efficiency of direct-cycle boiling reactor

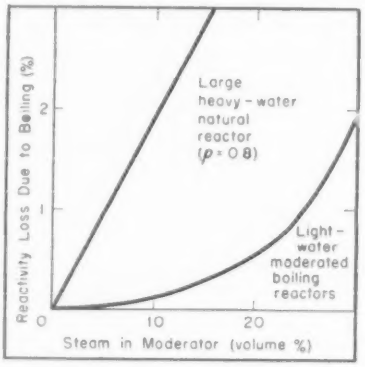


FIG. 3. Effect of distributed steam voids on two types of boiling reactors (illustrative curves)

boiling reactors are trivial. Of course, circulating pumps may be used, if desired, to boost reactor output.

Since steam is used directly, many of the usual thermal barriers within the heat exchanger and reactor are eliminated. Consequently, higher efficiencies can be obtained for the same fuel temperature, while tolerable thermal efficiencies can be obtained with reduced reactor pressures and temperatures (Figs. 1 and 2).

Future outlook. If and when reactor technology permits higher reactor temperatures and pressures, we can foresee corresponding improvements in boiling-water reactor performance. If steam could be generated within the reactor at the critical temperature, at 3,305 lb/in², a thermal efficiency of about 40% could be obtained. We may envisage gradual advances over the years in pressure vessels and corrosion technology until this ambitious goal is attained. Figure 1 indicates the extent of improvement possible in the efficiency of boiling reactors.

Application to smaller units. Boiling reactors are so simple that they can be constructed in smaller sizes than was hitherto deemed practical for power reactors. Low-power relatively inexpensive plants are feasible because many of the expensive components are eliminated, while reasonable thermal efficiencies can be obtained with low temperatures and pressures. In fact, aluminum cladding is sufficiently corrosion resistant for use in boiling reactors at temperatures that permit reasonable thermal efficiencies (*3*).

It is always easier to develop industrial interest in a device that can be tested on a modest scale. Our national experience is replete with examples of machines that grew up from small beginnings. Thus it seems good for the budding nuclear industry that a type of reactor is finally available that can be built in a size that is technically feasible but not financially unmanageable.

Boiling Reactor Development

Throughout the early part of the Manhattan Project, it was generally believed that such reactors would be unstable and would not operate (*4*). These conclusions were certainly supported by information available at that time. Speculative calculations suggested that reactors might require smooth and delicate control, whereas the very nature of boiling is rough and boisterous; so it was anticipated that the collapse of steam bubbles might initiate sudden unsafe fluctuations in reactivity and in power.

In 1947, during the planning of the watercooled submarine reactor, stability considerations were still unresolved, and high-pressure nonboiling water was chosen as the coolant for the "Nautilus" STR reactor.

Safety, Stability Requirements

During 1948, time was finally available for the crucial laboratory experiments necessary to resolve questions of stability, safety and performance of boiling reactors. From the standpoint of stability and safety under boiling conditions, reactors can be divided into two classes:

1. **Self-regulating reactors.** An increase in reactor power causes an immediate decrease in reactivity, which in turn reduces reactor power.
2. **Auto-catalytic reactors.** An increase in reactor power causes an increase in reactivity, resulting in further increase in reactor power. If the reactor operation is not otherwise limited, this condition may cause the reactor to destroy itself.

All the factors entering into the critical equation may be affected by boiling and bubble formation. These factors are: $\eta\epsilon pf$ and leakage.

Ordinarily, the largest effects of boiling are increases in: 1, resonance absorption due to expulsion of the moderator; 2, thermal utilization by expulsion of neutron-absorbing coolant; and 3, neutron leakage by expulsion of moderator and scatterer.

Change in thermal utilization is generally negligible for a heavy-water reactor, while change in resonance absorption is trivial for highly enriched reactors. Leakage is less important in large reactors. Changes in resonance absorption and leakage tend to make reactors self regulating, while the expulsion of a neutron-absorbing coolant, of itself, would make a reactor auto-catalytic.

Either a light- or heavy-water cooled reactor can be designed so that boiling will have the desired effect on reactivity. It is possible to construct reactors so that the reactivity decreases steadily as coolant is expelled. On the other hand, reactors can be propor-

tioned so that expulsion of the first small fraction of coolant only reduces reactivity slightly, while expelling twice as much coolant will reduce reactivity to a disproportionately greater extent. These trends are illustrated by the reactivity curves of Figs. 3 and 4.

Any reasonable degree of self-regulation can be provided without seriously compromising other reactor design criteria. Thus, practical boiling reactors can be designed so that steam formation will reduce reactivity and hold the power in check. Self-regulating boiling reactors can be constructed using various combinations of fuel, moderator, and coolant, some of which are listed in the table here.

Steam bubbles form rapidly. Time delays are extremely important in reactor self-regulation. Most thermal reactors have prompt-neutron lifetimes ranging from 10^{-5} to 10^{-3} sec. If a typical reactor has a lifetime of 10^{-4} sec, then a sudden increase in reactivity to 1% beyond prompt criticality would cause the reactor power to increase by a factor of 2.7 in 0.01 sec. To quench such reactivity excursion before the fuel plates melt, steam bubbles must appear within a few hundredths of a second. Therefore, experiments were started in 1948 (*5*) to determine the time delay inherent in the boiling process. Experiments of this type were continued and extended by J. M. West, J. T. Weills, H. H. Hooker, and R. Schiltz.

Water-filled metal tubes, ranging from 1 to 4 cm in diameter and from 10 to 30 cm in length, were heated suddenly by the momentary passage of a low-voltage alternating current. This current was furnished by the low-voltage windings of a transformer; in the later experiments, duration of the transformer-primary current surge was controlled by an ignitron. Sufficient power was available to heat the tube wall over 500° F within 0.01 sec. This condition corresponds to a momentary heat flux of many kilowatts per square centimeter.

Tests were performed both with saturated water and with sub-cooled water. A typical test record, obtained by H. H. Hooker and R. Schiltz, is shown in Fig. 5. Steam formed within the tube started to expell water within 0.003 sec after power was applied. Thus, it has become clear that the boiling process itself is fast enough to control any fluctuations in power due to boiling. In fact, it is hard to conceive of any thermal reactor runaway so rapid that it would outrun the bubble formation mechanism.

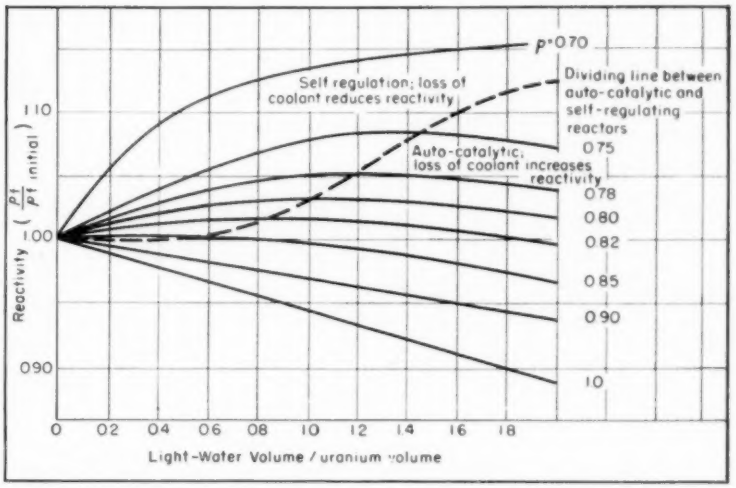


FIG. 4. Effect of light-water cooling on reactivity of natural-uranium reactors. Moderator is graphite or heavy water

Some Possible Material Combinations for Self-Regulating Boiling Reactors

Fuel	*Moderator*	*Coolant*	*Self-regulation requirements*
Natural uranium	D_2O	D_2O	None
Natural uranium	D_2O	H_2O	Limit on amount of coolant—see Fig. 4
Natural uranium	Graphite	H_2O	Limit on amount of coolant—see Fig. 4
Natural uranium	Graphite	D_2O	None
Partially enriched uranium	H_2O	H_2O	Limit on (water/uranium) ratio
Natural uranium—enriched control rods	H_2O	H_2O	Limit on (water/uranium) ratio
Fully enriched	H_2O	H_2O	Must be small

Power higher than anticipated. It now remained to demonstrate that useful amounts of power could be removed from a reactor by boiling. In 1952, laboratory experiments were started to determine how much power could be removed by natural circulation under boiling conditions. Such a test setup is shown in the illustration on p. 43. These experiments have been continued and extended by E. A. Wimunc, P. Lottes, A. S. Jameson, and C. Soppet.

In a reactor, the amount of reactivity controlled by steam bubbles is probably limited, so it should be rationed most carefully. Consequently, the factors studied are those that influence relations of steam void fraction to power.

It had been feared that very little power could be extracted from a reactor without exceeding the practical limitations on steam voids. This incorrect conclusion was based on an erroneous estimate of the rate of rise of steam bubbles within the boiling region. Original estimates, based on Stokes law, indicated that the steam bubbles would not rise faster than 3 ft/sec.

An X-ray densitometer has been used to measure the steam void fraction within an electrically heated array of vertical plates. X-rays were obtained from a thulium-170 source (NU, May, '54, p. 35). This radiation passed through the boiling section and was detected with a sodium iodide crystal and photomultiplier. Output current from the photomultiplier was connected to a fast-response recorder. This recorder could then be used to measure either steam void fraction or its variation within the heated section.

Such measurements have been made

with vertical plates varying from 9 in. to 5 ft high, spaced from $^1/_{16}$ to $^3/_4$ in. apart, with water saturation pressures from 10 to 260 lb/in² absolute. The steam bubbles escaped much more rapidly than would be predicted by Stokes law, assuming discrete, spherical bubbles. We have attributed this discrepancy to steam channelling, although we cannot yet describe these steam passages through the water on a quantitative basis. Steam velocities of over 60 ft/sec have been observed at atmospheric pressure, while velocities of about 10 ft/sec were observed at 260 lb/in² absolute. Typical data are shown in Fig. 6.

Putting these results in other terms, we found that the power that could be removed by natural boiling convection was many times greater than has been anticipated. Figures 7 and 8 show power and voids in boiling heat-transfer tests. For reactors operating at 600 lb/in² absolute, data in Fig. 7 indicate that at least 40 kw of heat can be removed from each liter of core volume with 19% average steam voids in the reactor core. Much higher outputs might be obtainable with still higher pressures but present data do not allow reliable extrapolation above approximately 1,000 lb/in². These outputs could be increased still further through use of forced circulation.

Borax experiment. During March, 1952, we proposed that an experiment be conducted at the Reactor Testing Station in Idaho to determine whether formation of bubbles would quench a reactor runaway and whether a boiling reactor would operate in a stable fashion. On June 9, 1952, the LITR at Oak Ridge National Laboratory was operated a short time under boiling conditions, although the bulk water temperature within the reactor core was kept well below the boiling point.

During the past summer, extensive tests at the Reactor Testing Station on a light-water boiling reactor have confirmed that bubble formation can quench extremely rapid reactor runaways and that reactors can be operated continuously in a stable fashion under boiling conditions. As announced by Commissioner Smythe (*2*) and Dr. Hafstad, Argonne National Laboratory is now engaged in design and construction of a 20,000-kw (heat) boiling reactor. Since this reactor will be of the regenerative type, it will contain both U^{233} and U^{238} so that in the later stages

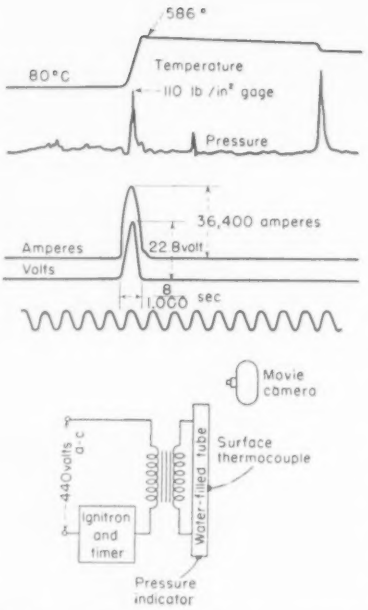


FIG. 5. Typical record of water expulsion test. Expulsion from $^5/_{16}$-in. inside diameter, 0.015-in. wall copper tube 6 in. long started in 0.003

of operation some of the plutonium produced in the reactor will be consumed.

Remaining Uncertainties

Perhaps it would be appropriate to discuss the major remaining uncertainties in boiling-reactor operation. Probably stability of operation still remains the outstanding uncertainty. Last summer's experiments established that a reactor could operate in a stable fashion with enough steam bubbles to generate substantial useful power. Naturally, there may be reactor designs where the tolerable volume of bubbles is much higher, and there are designs where the effect of bubble formation on stability is reduced. Thus, it may be feasible to run boiling reactors at much higher power densities than was possible last summer. Only experiments can establish final limitations of power density and steam void fraction that can be tolerated in boiling reactors.

Little radioactivity in steam. A minor uncertainty in the direct-cycle boiling reactor results from the slight radioactivity in the steam, and the possibility that some of this radioactivity might be entrained on the turbine blades. This aspect of direct-cycle boiling reactors seems to have caused undue concern. Almost all the radioactivity in the coolant of a water-moderated reactor is due to short-lived oxygen decay. There are two principal activities in oxygen

$$O^{18} + n_{\text{thermal}} \rightarrow O^{19}(29\ \text{sec}) \rightarrow F^{19} + \beta + \gamma\ (1.6\ \text{Mev})$$

and

$$O^{16} + n_{\text{fast}} \rightarrow N^{16} + p$$
$$N^{16}\ (7\ \text{sec}) \rightarrow O^{16} + \beta + \gamma\ (6\ \text{Mev})$$

The second reaction predominates, but neither reaction is very probable, so that the actual activity encountered in the coolant of a water-cooled reactor is never very high, rarely over 1,000 times tolerance.

The difficulty is that the gammas produced in N^{16} decay are extremely hard, so that large thicknesses of dense shielding are required to reduce the radioactivity by a relatively small factor to a tolerable level. The velocity of steam can be many times higher than the velocity of water, since its density is much lower. Thus the amount of coolant contained in the pipes external to the reactor is much lower when the coolant is handled in the form of steam than when liquid water is used. Since the source of radiation is reduced by a large factor, it is by no means certain that shielding is actually required around the external cooling circuit of a boiling reactor. Probably all that is required is to avoid the immediate neighborhood of the cooling system during reactor operation. Even then, the pipes, if unshielded, could probably be approached for several minutes at a time without exceeding established biological radiation tolerances.

Since the oxygen activities decay within a few minutes after reactor shutdown, they do not interfere with normal periodic maintenance. If present, long-lived activities within the turbine casing must be due to entrained particles of activated materials from the reactor or cooling system. However, the boiling process itself provides an excellent separation of activity so that the great bulk of radioactivity is concentrated within the reactor tank. Calculations, substantiated by experience last summer, suggest that the amount of activity entrained on the turbine should not be much greater than the activity of a radioactive dial on a wrist watch. Thus no unique problems in maintenance are anticipated.

It must be remembered that this low activity is a result of the vast bulk of fission products and all the neutrons

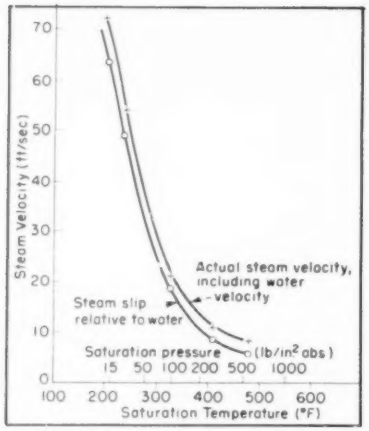

Steam Velocity (ft/sec)
Actual steam velocity, including water velocity
Steam slip relative to water
Saturation pressure (lb/in² abs)
15 50 100 200 500 1000
Saturation Temperature (°F)

FIG. 6. Measured steam velocity in 5-ft-high section of ½-in. water passages with natural circulation. Curves calculated from data of E. Wimunc and A. Jameson, except for 600-lb in.² data, which was obtained by C. Soppet for ¼-in. water passages

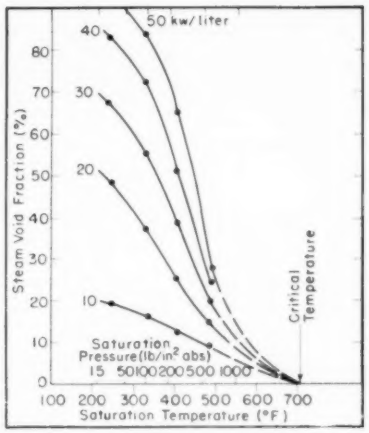


FIG. 7. Measured steam voids with saturated water fed to 5-ft-high section of ½-in. water passages (natural circulation). Based on experiments of E. Wimunc, A. Jameson, P. Lottes, S. Untermyer; data at 600 lb/in.² from C. Soppet

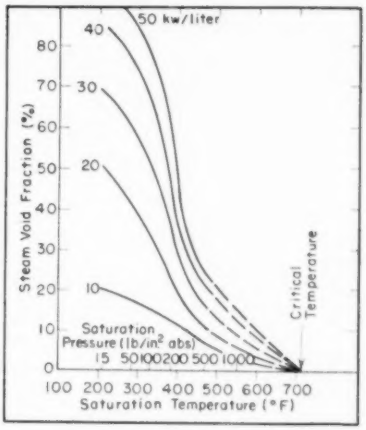


FIG. 8. Estimated steam voids feeding condensate into reactor at 120° F with natural circulation. Forced circulation could be used to increase output without increasing temperature

being retained within the reactor tank. This is one of the major advantages of a solid-fuel reactor over one using a homogeneous fuel solution. In a solid-fuel reactor, even a major rupture in the fuel element cladding only releases a minute fraction of the total fission-product activity. As the great bulk of this activity is nonvolatile, it remains in the reactor where it is harmless.

Low Leakage Rates

One problem is unique to the heavy-water version of the boiling reactor. Since heavy water is an extremely expensive coolant (worth $80/lb on the world market in Europe) any appreciable leak will represent a serious economic loss. Even in the largest plants, heavy-water makeup cannot exceed a few gallons per day. Such low leakage rates have never been attained with steam plants, but never before has such an incentive existed to reduce leakage rates. While reduction of leakage is a straightforward problem, it may present some serious practical difficulties.

Simplicity of Operation

A boiling reactor, operating against a fixed pressure, will operate at a fixed temperature, since the saturation temperature of water is uniquely established by the pressure. Such a reactor, however, possesses a power coefficient of reactivity, so that there will be a fixed correspondence between the amount of reactivity controlled by steam voids and the reactor power. If the control rods are withdrawn, then the reactor power will increase until steam is formed fast enough so that the steam voids within the reactor have increased by an amount that just offsets the control-rod withdrawal. Such a reactor would operate without continuous control adjustment, providing the outlet pressure was regulated.

In a power plant, where load changes may be expected momentarily, the situation becomes more involved. Since the reactor contains a large volume of saturated water, it will momentarily deliver enough steam to prevent rapid changes in pressure within the steam dome above the reactor. If the turbine suddenly demands more steam than is generated by fission within the reactor fuel, then the saturated cooling water will "flash" into steam to provide the deficiency. Flashing water into steam will introduce steam voids that will tend to decrease the reactor power. To offset this, the control rods must be withdrawn until steam generation by fission heat balances demand.

With our limited experience in operating boiling reactors it is not yet possible to resolve all questions definitely. Future experience with the 20,000-kw experimental boiling reactor should indicate practical procedures for handling operating problems.

Even though some uncertainties still remain, we believe the boiling principle can provide inherent safety, reduce reactor plant costs, and establish a clear basis for competitive nuclear power. General Electric considers the boiling reactor one of the most promising for nuclear power (p. 51).

* * *

Two specific laboratory experiments were necessary before boiling reactors could receive serious consideration. R. Schlitz developed the water expulsion equipment and fast recorders and thermocouples needed to obtain precise results. These results have been analyzed by H. H. Hooker and R. Schlitz. E. Wimunc designed and constructed various sizes of electrically heated boiling test sections. With this equipment Wimunc used an X-ray densitometer to determine the relations of power density and steam voids. This work was analyzed by P. Lottes. More recently, Wimunc's work has been extended to higher pressures by C. Soppet. A. Jameson directed all these heat-transfer experiments and played an important role in analysis and correlation of this data.

Since it is expected that details of these experiments will be published in appropriate technical journals, descriptions of this work have been limited to those portions pertaining directly to reactor design. Only because of these experiments has it been possible to begin development of direct-cycle boiling reactors.

BIBLIOGRAPHY

1. NUCLEONICS **12**, No. 3, 75; No. 4, 78. (1954)
2. Joint Congressional Committee on Atomic Energy, "Report of the Subcommittee on Research and Development on the Five Year Power Reactor Development Program Proposed by the Atomic Energy Commission" (U. S. Government Printing Office, Washington, 1954)
3. J. R. Drahly. Corrosion of aluminum in high temperature water, lecture in "Short Course in Corrosion" (National Association of Corrosion Engineers, University of California, 1953)
4. Cooling a reactor by the latent heat of vaporization of a liquid, OSRD Case S-97. Captain Lavender's letter contains the following statement: " . . . in view of . . . indication that no way has been worked out for controlling a reactor of the type under consideration, the case will be given inactive status until such time as an operative device can be disclosed."
5. S. Untermyer. Reduction in reactivity of a heterogeneous reactor by expulsion of coolant, ANL-WPB-60 (1950)

U. S. Power Reactor Program.. ..Goal: Economic Power in 10 Years

This nation is now getting set for an all-out push to achieve nuclear power that will be competitive within the borders of the United States. The next five years will see a strong cooperative program carried out by the Federal government and private industry. The government activity is already clearly defined and under way. Industry has set its sights and is moving ahead as fast as Federal law will permit. Here are details of these projects

CONSIDERABLE OPTIMISM now exists that the period 1959–1964 will see construction start on the first competitive industrial nuclear power plant.

This statement is based on facts brought out at the May 24th conference of the Atomic Industrial Forum in Washington, D. C.

These next years will be expensive and crucial ones. Rep. W. Sterling Cole, chairman of the Joint Committee on Atomic Energy, estimated that $0.5-billion will have to be spent on research and development over the next five years and "perhaps an additional billion dollars for the construction of prototype plants and pilot models between now and 1964." General descriptions of the reactors in AEC's five-year program have been presented (NU, May, '54, p. 72).

There are many different ideas as to what the best approach to nuclear power is. In fact, one informal poll showed 80 different ideas. Alvin M. Weinberg, Research Director at Oak Ridge National Laboratory, put it this way:

"Never has there been a technology where each step has been so unwieldy and yet where there have been so many eloquent protagonists for each (reactor) scheme. But it is not eloquence that will determine success, nor the skill of the protagonists. Rather, success will be determined by the guts of the protagonists. Some plans that don't look too good today will turn out successful because of the vigor and aggressiveness of the people involved."

This meeting, the Forum's second, saw considerable vigor displayed by advocates of the principle systems being developed.

THE NINE APPROACHES

The approaches taken by the leading groups were explained by a representative from each organization.

Oak Ridge National Laboratory—A. M. Weinberg, Research Director

Successful operating experience with HRE-1 has demonstrated the technical feasibility and innate safety of homogeneous reactors. Of 1,950 hr above critical, it has operated 720 hr above 100 kw. Over 24 months, liquid was circulated for 4,498 hr. Top power level attained was 1,600 kw.

Stability is inherent in homogeneous reactor systems. Their negative temperature coefficients make them power-demand responsive. To prove this, HRE-1 was operated at low power and the fuel solution was suddenly cooled drastically. Power level spurted by a factor of a million within a few milliseconds—but then it settled down to a steady-state level.

The variety of species of homogeneous reactors depends on the solvent used for the uranium fuel—light water, heavy water, or one of the liquid metals. Heavy water has advantages from the nuclear point of view, but it boils at 100° C and its critical temperature is 375° C.

The trend toward high thermal efficiencies has been motivated by the desire to reduce the effective cost of fuel (particularly in the case of coal). But, if the fuel cost (and thus, steam cost) is extremely small, then low pressures might be quite satisfactory.

Thermal efficiency is not the only criterion. Consideration must be given to all elements of cost, e.g., such things as burnup, chemical processing, and efficiency of utilization of plant materials (or fixed-cost efficiency). A low-thermal-efficiency plant that has a high fuel efficiency might have an outstanding over-all efficiency. It is in this dollar efficiency that homogeneous reactors have a great potential advantage.

There appear to be three disadvantages to homogeneous reactors: 1, circulation of extraordinarily radioactive materials at "uncomfortably" high pressures (the system must be absolutely leaktight—that this problem can be surmounted is evident from the fact that HRE-1, which circulated the equivalent of a ton of radium—30 curies per cm^3 of liquid at 1,000 psi, has never had a high-pressure leak during operation; 2, "wicked" corrosion problems—uranyl sulfate is strongly acid at high temperatures; 3, problems attendant upon the handling of fluids and materials arise because of the desire to have a "simple" system—even so, the materials-handling problems are not as severe as those of mechanical design.

Westinghouse Atomic Power Division—C. H. Weaver, Manager

Westinghouse is designing the reactor and primary cooling circuit for this country's first large-scale atomic power plant, the PWR.

We were given the following general specifications for PWR: 1, at least 60 Mw of electric energy; 2, light-water-cooled-and-moderated slightly-enriched-uranium reactor; 3, 600 psi (sat.) or higher steam; 4, fuel-element life as long as possible between reprocessings; 5, refuel with minimum shutdown period; 6, simplified reactor controls; 7, central-station type generating equipment; 8, conventional steam, electric, and other

auxiliary systems; 9, commercial equipment standards; 10, concrete shield; 11, minimum construction cost; 12, minimum operating cost consistent with other requirements.

The main coolant system, which serves both to absorb heat generated by the reactor and to deliver heat to the steam generators, will consist of four loops operating off the reactor vessel. Each loop consists of a pump, steam generator, shutoff valves, and interconnecting pipe. The pumps continuously circulate coolant water between the reactor and the steam generator. The steam generator is the connecting link between the primary system and the steam system.

Water in the primary plant will circulate at a pressure of some 2,000 psi to prevent boiling in the core and to eliminate cavitation problems. The average temperature of the primary plant water will be maintained at about 525° F.

Primary coolant loops are so designed that rated plant output is produced with three of the four loops operating. The fourth loop will normally serve as a spare. The loops divide the load equally, and the steam generated by each is fed to a steam header and delivered to the turbine. To produce 60,000 kw net with 3 loops operating, the pump in each loop circulates water at a rate of about 16,000 gal/min; this requires about 1,000 hydraulic horsepower for each pump. All surfaces of the primary plant that come in contact with high-temperature primary coolant water probably will be made of stainless steel. All components will be designed to prevent leakage of coolant water from the primary system.

The primary plant also involves a number of auxiliary systems. These accomplish such necessary functions as maintaining the primary system pressure at 2,000 psi, filling and draining the primary system, purifying the water, providing for reactor control, dissipating the reactor decay heat after shutdown, etc.

The primary water is maintained at 2,000 psi by a pressurizing tank that floats on the system and is connected to one of the reactor outlet pipes. This tank is normally filled with about equal volumes of water and saturated steam at more than 600° F.

The reactor core will consist of a geometrical pattern of closely-spaced fuel elements. The elements will contain more than 10 tons of slightly enriched uranium. The fuel elements will be protected by a corrosion-resistant material designed to prevent the coolant water from becoming contaminated with particles of uranium and fission products. Maximum surface temperature will be less than 636° F.

The reactor container, as well as the entire plant, is being so designed that fuel elements of various shapes and materials of various types can be used in cores following after the first core.

The reactor vessel, which contains the core, will be built large enough to accommodate cores physically bigger than the first one. This shell will consist of carbon steel clad with stainless steel. The cylindrical wall of the vessel will be penetrated by the four inlet and four pipe outlet connections for the four main coolant loops. A contract for the design and manufacture of this vessel is being negotiated.

Steam generators will consist of two major components: the heat exchanger portion, and the steam drum. The heat exchanger will consist of a bundle of stainless steel tubes, the ends of which will be welded into heavy tube sheets. The entire assembly will be enclosed in a steel shell. Primary coolant will flow inside the tubes. Steam-plant feed water will be converted to steam as it flows upward over the outer surface of the tubes. The steam will rise to the steam drum where it will be dried by passing through a conventional steam separator. The steam will leave the steam drum at 600 psia saturated. We have placed firm price orders for the four steam generators. Foster Wheeler Corp. will build two and Babcock and Wilcox Co. will build two. The relatively small additional cost of splitting this order is more than justified on the basis of additional knowledge to be gained, since the two companies are using designs that differ.

The pumps will be single-stage centrifugal units driven by induction motors of the canned type. Use of canned motors permits elimination of the maintenance and leakage problems likely to be encountered if rotating seals were employed. Westinghouse Atomic Equipment Department is designing a prototype pump and motor. The PWR pumps will involve an output of about 1,000 hydraulic horsepower, and an input of about 1,200 kw.

Primary coolant stop valves will be of the gate type. At least some of these valves will be designed to permit remote operation. They will be hermetically sealed and will function hydraulically. A prototype main coolant valve is on order from the Crane Company. The primary coolant system's stainless-steel pipe will have an outside diameter of about 18 in.

The reactor and heat exchangers will be located underground in concrete and steel structures. These underground structures will provide protection to operating personnel and the surrounding area in addition to the many protective devices in the reactor itself.

North American Aviation, Inc.—C. Starr, Director, Atomic Energy Research Dept.

The present conception of a sodium-graphite-reactor central station plant includes primary and secondary sodium systems and a steam boiler with the reactor located in a steel tank below ground level. Uranium fuel elements are suspended vertically in channels through which the sodium circulates. Each fuel cell consists of graphite in a metal can with the coolant channel at the center. The assembly completely fills the tank. Liquid sodium enters the bottom of the tank at about 500° F and leaves the top at 900°–1,200° F.

Because the technology of handling liquid sodium at high temperatures is

Atomic Industrial Forum

Sponsor of the meeting reported on these pages, the Atomic Industrial Forum is now a going organization. It has held two highly successful, well-attended meetings, and has others planned for this year.

In addition to holding meetings, the Forum is now an official AEC depository library. It will supplement AEC documents with other pertinent books and literature.

Membership in the Forum is growing rapidly. They recently passed the 118 mark on organization members.

Information on its activities can be obtained from the Forum at 260 Madison Ave., New York 16, N. Y.

undeveloped, the capital investment in a central-station size plant now might be about $250 per installed kilowatt of electrical output, not including the cost of the fuel inventory. This investment eventually can be decreased to $150/kw.

The cost of power from a sodium-graphite-reactor power plant, including cost of fuel and all operating costs, would be in the range of 8–10 mills/kwh on the basis of present costs. If reasonable optimism is applied to the improvements in construction costs, performance, and operating costs, this type of plant eventually can produce power in the range of 4–5 mills/kwh.

Development of this type of reactor will be implemented by a sodium-reactor experiment.

Argonne National Laboratory—W. H. Zinn, Director

ANL is working on two units to be constructed as part of the five-year program. The boiling experimental reactor (BER) will be completed 2 years before the intermediate-size experimental breeder reactor (EBR-2).

To lower fuel costs, two general schemes are being pursued: 1, long burnup of natural uranium or slightly enriched fuels (BER, SRE, PWR); 2, reduce cost of reprocessing irradiated fuel (HRE-2, HTR, EBR-2).

In the long-burnup proposals, it is supposed that the whole fuel cost is the purchase price of natural or partially-enriched uranium plus the cost of providing storage for this material after it has been exposed in the reactor. Long burnup is useful in getting an atomic power industry started; but because too little of the uranium (only about 1%) is used, it is not necessarily what should or will be done in the long pull. It does not make good business sense to place 99% of the fuel in permanent storage. A long-burnup reactor producing 150 Mw of electricity would call for the disposal of about 20 tons of U^{235} and 200 kg of Pu^{239} per year. It would be a better financial gamble to reprocess such materials than to mine and process lower grade uranium ores.

For a discussion of boiling water reactors, see p. 43.

EBR-2 operates on the Pu-U^{238} system and, therefore, incorporates the idea that the fuel will be reprocessed and that U^{238} will be consumed.

We have satisfied ourselves with EBR-1 that a reactor of this design, fueled with plutonium, will have a breeding ratio substantially more than 1. Even supposing that the market for fissionable material permits a sale price of only $20/gm (fuel value only), the sale of byproduct Pu can be a substantial source of operating revenue.

EBR-1 was not intended to provide extensive engineering information. But it has been remarkably successful as an engineering device. It has operated $2\frac{1}{2}$ yrs without breakdown except for one serious leak in a heat exchanger. This was repaired quickly, showing that maintenance in a radioactive sodium system is not too difficult. Fuel insertion and removal has been smooth and satisfactory. Coolant temperatures of 660° F have been obtained easily. The original design power level of 1,000 kw was from the beginning raised to 1,400 kw and, indeed, is only limited by air cooling for auxiliaries.

High specific power (0.5–1.5 kw/gm of Pu) must be realized in a successful power breeder. Further, pumps, heat exchangers, valves, and all hardware items in EBR-2 will be of a size and kind suitable for large-scale application. Temperature of the sodium coolant delivered to the steam generator will be limited only by corrosion. To simplify the radioactive-sodium system and to facilitate shutdown cooling, a new arrangement of reactor and cooling system, called tank type, is proposed. Because the fuel will be plutonium, fuel processing and fabrication of fuel elements containing alpha-active material are a basic concept of the plan.

Nuclear Power Project; Foster Wheeler Corp., Pioneer Service and Engineering Co., and Diamond Alkali Co.—C. R. Barthelemy, Project Engineer

To keep nuclear-power costs down, this group's studies have been aimed at —keeping reprocessing and handling costs as low as possible, and achieving long burnup or continuous reprocessing.

Four major types of reactors are considered possible producers of competitive power: 1, circulating-fuel thorium breeder; 2, fast breeder with inexpensive processing; 3, sodium-graphite reactor; and 4, pressurized-water type, with or without boiling.

We felt that the circulating-fuel thorium breeder had these advantages: 1, inherent stability; 2, fuel easily handled remotely, continuously, and with no fabrication difficulties; 3, breeding; 4, possibility of producing high-purity fuel; 5, use of low-cost structure. However, experiments showed that the two-phase system loses its "liquid" stability. Structural problems began to emerge. Thus, this reactor type has been dropped from consideration.

The group now is studying other fluid-fuel thermal reactors, i.e., the aqueous homogeneous power breeder on which basic research is being conducted at ORNL.

Dow Chemical-Detroit Edison and Associates Atomic Power Development Project*—A. P. Donnell, Project Manager

This group favors a large fast breeder. It is conducting research on fuel elements, coolant, controls, and mechanical handling. Solid fuel elements are favored and studies have included work on remote fabrication and close integration of fuel-element fabrication with some form of metallurgical process. Means of attaining high breeding ratios are being investigated.

Fluid fuels and integrated processing are being investigated. Fission-product uses and markets are being developed.

Nuclear Power Group†—T. G. LeClair, Chairman, Operating Committee

The pressurized-water reactor appears to be the best design for economically generating power in the near future. Since the light-water version is receiving considerable attention by others, we designed and estimated the cost of a heavy-water natural-uranium fueled plant.

Minimum investment was desired; but the unit had to be large enough to extend cost data to sizes needed for a large power system. Since unit cost for a D_2O-moderated plant drops very sharply as plant-size increases, a 50-Mw plant and a 150-Mw plant were chosen for comparison.

This appears satisfactory for a single turbine-generator supplied by a single reactor, even though steam pressure and temperature are extremely low. In this design, D_2O is both moderator and coolant. The reactor and primary coolant circuit operate at 600 psi. Saturated steam is produced in a heat exchanger system and delivered to the turbine throttle at 175 psi. While the design includes D_2O purification, no

* Consists of 26 project companies.

† Consists of five companies: American Gas and Electric Service Corp., Bechtel Corp., Commonwealth Edison Co., Pacific Gas and Electric Co., and Union Electric Co. of Missouri.

General Electric Favors these Power Reactors

	Boiling-reactor plant	*Coal plant*	*Graphite-reactor plant*
Plant data			
Electrical output (net capability)	300 Mw	300 Mw	700 Mw
Plant util. factor	0.8	0.8	0.85
Steam temperature	450° F (sat.)	1,000° F	375° F (sat.)
Pressure (lb/in² abs.)	421	1,450	180
Net plant thermal eff.	24%	35%	23%
Heat generated	1,250 Mw	857 Mw	3,000 Mw
Investment			
Physical plant	$195/kw	$140/kw	$214/kw
Land	2	2	1
Engineering	15	11	17
Startup	14	7	17
Nuclear fuel inventory	17	0	28
	$243/kw	$160/kw	$277/kw
Power cost			
Fixed charges	4.65 mills/kwh	3.0	5.2
Operating cost	0.70	0.5	0.6
Fuel	1.35	3.4*	1.0
Total	6.7 mills/kwh	6.9	6.8

* Coal at 35¢ million BTU

provision is made for fuel processing.

Total investment in a 50-Mw plant is estimated at $38-million or $760/kw gross capacity. When size is increased to 150 Mw, capital cost becomes $60-million or $400/kw.

We used unit costs for U, D_2O, Zr, and fuel fabrication that are relatively conservative. Unit cost of uranium, for example, was a typical value used by others making evaluation studies. Heavy water, due to its high price, accounts for a large portion of the capital cost. Fabrication of zirconium into fuel elements is a factor upon which no firm price can be established on a quantity basis at this time.

It was assumed that fixed charges were 15%, that fuel could be irradiated to 10,000 Mw-days/ton,‡ and thereafter would have no value. With these assumptions the 50-Mw plant would produce power for about 22 mills/kwh and the 150-Mw size for 12 mills. This plant could be built now and operated successfully. However, its cost figures are not competitive with power from modern coal-fired plants and no proposal has been made for construction.

The actual picture is more optimistic because there are so many opportunities for cost reductions. If the plant were increased to 200 Mw, production cost would be reduced to about 10 mills/kwh. A 300-Mw plant, using two turbines with a single reactor, has a still lower capital cost per kw. Recent information indicates reduction in cost of D_2O. If a 300-Mw plant were built with cheaper D_2O and less costly fuel-fabrication, it could become attractive, perhaps as low as 7 mills.

In the meantime, Nuclear Power Group is turning its attention to other designs whose full-scale feasibilities are less tangible but that appear to hold great promise for economical power generation. We are beginning a boiling-reactor design and contemplating preliminary homogeneous reactor study.

‡ This means that 1 ton of uranium might produce 240,000,000 kwh.

General Electric Co.—F. K. McCune, General Manager, Atomic Products Division

We believe that: 1, electric companies will be owning and operating a number of atomic power plants within the next ten years; 2, some of these will be full-scale and will generate electricity at competitive costs, possibly within five, certainly within 10 years; 3, this will be accomplished without Government subsidy for production plant construction or operation, and with Government supplied fuel priced at cost-of-production levels; 4, two nuclear reactors best suited for earliest and most effective competition with conventional fuel plants in this country are (a) the light-water-moderated-and-cooled boiling reactor and (b) the graphite-moderated light-water reactor.

Cost estimates are shown for both types of reactors in the table, along with costs of a coal plant.

We have many reasons for being very enthusiastic about a light-water boiling reactor. Not the least of these include the many similarities of this plant to conventional steam plants. Its adoption by the electric utility industry should be relatively easy. The moderator and coolant are both ordinary water which the industry is used to handling. Chemical separations plants are not necessary. The boiling reactor has demonstrated safeguard advantages so that operating companies should be able to choose plant sites available within their systems.

Fuel costs in this reactor include the estimated cost of enriched uranium, the cost of other materials which may be used, and the fabrication of complete canned fuel elements impervious to water. The most important assumption, however, is the exposure which is necessary for this fuel element to reach before it has to be discharged from the reactor. An exposure of 10,000 Mw days/ton is assumed. This is equivalent to 1% burnup.

The other reactor type shown in the table is a direct descendant of the graphite-moderated water-cooled reactors with which we have been producing plutonium at Hanford since 1946. Thus the cost estimates in the table are derived from actual construction experience. The basic engineering is essentially done.

Monsanto Chemical Co.—P. Powers, Director, Atomic Project

Ideally, a power reactor will yield three sources of income: 1, heat to produce electricity; 2, nuclear fuel; and 3, chemicals produced by radiation (polymers, penicillin, etc.).

Radiation-production of chemicals is considered an important economic factor. Much of the Monsanto group's effort is along this line. Revenue from sale of radioisotopes is considered to be of negligible economic importance.

Monsanto considers sodium-graphite reactors and pressurized-water reactors suitable for construction soon. With either system, the production of power plus Pu or U^{233} could give the government a good deal on its fissionable material purchases. END

Scintillation Counting of Natural Uranium Foils

Advantages of this technique for measuring reactor flux distribution include:

- **Foils, incorporated in fuel, do not affect fuel-element geometry**
- **Neutron spectrum corrections are eliminated**
- **Scintillation counting rate is faster than that of G-M counting**

By ROBERT C. AXTMANN* and JAMES S. STUTHEIT*
Argonne National Laboratory
Lemont, Illinois

FISSION-PRODUCT ACTIVATION and U^{238} capture activation of uranium foils have been separated by means of a NaI(Tl) scintillation crystal spectrometer. With this method, one can determine the spatial distributions of the fission-producing and "resonance" (epi-cadmium flux captured in U^{238}) portions of a reactor neutron flux.

Special problems often arise in making these measurements by the foil activation method. In heterogeneous piles, the pertinent fission-producing flux measurements are in the fuel itself since both the magnitude and the spectrum of the flux may be vastly different even a short distance into the moderator. If the foil is placed *within* the fuel, however, two additional difficulties arise: (1) the foil and/or its holder may affect the flux by reason of their neutron absorption, and (2) the geometry of the fuel element is altered so as to affect the quantity measured.

The most common method for studying fission-producing flux is to assume that this flux is strictly proportional to the thermal flux and then to measure the latter. A variety of foil materials, such as gold, indium, copper, or manganese, are exposed, and the induced beta activities are measured with thin-walled G-M tubes. If the foil is a resonance absorber, however, difficulties are encountered when making detailed measurements near fuel or control rods. The epi-cadmium flux tends to remain fairly constant throughout a heterogeneous pile whereas the thermal flux may suffer radical depressions. Thus, corrections must be applied to the data to account for the changing cadmium ratio; the net effect is that the measurements are doubled.

Often the number of such measurements, as described previously, is sharply limited by the number of foils that can be counted conveniently in the G-M tubes. Because of high dead-time corrections, the counting rates are kept purposely low. Then, again, reproducibility of results is often poor with end-window or thin-walled G-M tubes because the number of beta particles scattered into the counter from the walls of the counting pig varies significantly with sample position.

Fission-Producing Flux

Natural uranium foils meet many of the difficulties of previous methods. Fabricated into convenient shapes (such as pins), the foils can be incorporated into the fuel and require no special holders.

Counting is done with a NaI(Tl) crystal spectrometer similar to several described in the literature (*1*). To measure the fission-producing flux activation, the bias of the discriminator is set at such a level that only gamma rays more energetic than 0.5 Mev are counted. This not only eliminates much of the natural activity of the uranium, but completely discriminates against the gammas and X-rays arising from the decay of U^{239} or Np^{239}.

With one exception, the reported gammas for these two decays lie below 0.275 Mev (*2*). The exception is a 0.91-Mev gamma (*3*) assumed to be in cascade with the 73-kev gamma that follows the beta emission of U^{239}. A search for this particular gamma ray, using the NaI(Tl) crystal spectrometer, failed to disclose any indication of its presence, at least as a photoline. The failure to observe it may be due to (1) a high internal-conversion coefficient, (2) a low photoelectric-effect cross section for 0.9-Mev gammas in NaI, or (3) the nonexistence of the gamma ray. Feather has presented convincing arguments against the accuracy of Slätis' observation (*4*). Since the Compton edge for a 0.91-Mev gamma would lie well below 0.5 Mev, if the gamma exists, it is not being detected to any appreciable degree in the arrangement described here.

A thermal neutron flux of 10^7 for 20 min activates a 0.5-gm uranium foil sufficiently so that 10,000–20,000 counts/min may be observed 1 hr after exposure. The usual thinness requirement encountered in beta counting may be ignored (if the foil is not exposed in too high a flux gradient) because of the metal's transparency to greater than 0.5-Mev gammas.

Since the decay of fission-product gammas does not follow a simple law, correction to saturated activities is difficult. *Relative* values of foil activation are obtained by one of two procedures. If the exposure time of the foils can be closely controlled, an empirically obtained plot of gamma ac-

* Employees of E. I. du Pont de Nemours and Co., Inc., on loan to Argonne National Laboratory. PRESENT ADDRESS: E. I. du Pont de Nemours and Co., Inc., Savannah River Laboratory, P. O. Box 117, Augusta, Ga.

tivity vs time serves to normalize all foils in a set to a predetermined time after irradiation. If it is impossible to obtain standard irradiation times, one foil out of the set is used as a "standard foil" and its activity is followed closely during the counting of the entire set, on the same or similar apparatus. Using the same apparatus, of course, tends to cut down the total number of foils that may be counted.

Because of the high counting rates obtainable with scintillation counters, as many as forty foils may be counted in one hour with 1% or better statistics. Since the absorption cross section of 0.5 gm of natural uranium is so small (less than one-tenth that of a 1 cm × 1 cm × 0.005 in. indium foil—the type often used in such measurements), a great many such foils may be placed in the moderator of a pile without appreciably depressing the flux. Such a procedure is advantageous when accurate measurements of thermal utilization or diffusion length are made.

Resonance Flux

The same foils that are used for measuring fission-producing flux may be used to determine relative values of the resonance flux, if the amount of U^{238} thermal-capture activation is subtracted. The measurement is, of course, direct if the foils are cadmium enclosed. The fission-product and U^{239} gammas are allowed to decay for three days. The window of the differential pulse height analyzer of the crystal spectrometer is then set on either a characteristic X-ray or on the photoline of one of the γ-rays arising from the 2.33-day decay of Np^{239}.

The graph on this page shows a spectral curve taken with the scintillation spectrometer on a sample of natural uranium metal three days after irradiation in a pile. The large peak, near 100 Kev, is the sum of two X-rays very close together reported by Slätis (*3*) as having energies of 97.3 and 98.3 kev and being the *L* and *M* lines of the K_α radiation of Pu^{239}. At the left side of this peak is a small bulge that appears more plainly if greater amplification is used. This bulge is probably due to the combined photolines from the 61 and 67 kev gammas of Np^{239}. The two peaks to the right of the largest one are the photolines from gammas at 0.206, 0.227, and 0.275 Mev. The 0.206 and 0.227 Mev lines are not resolved. The 0.411-Mev line from Au^{198} is shown as a dotted calibration line.

Any of the three major peaks shown in the left-hand curve of the illustration may be used for measuring relative activities. An experiment to check (1) the absence of appreciable fission-product activity after three days and (2) the proper half-life of Np^{239} decay was performed as follows: a natural uranium pin was exposed for 20 min in a thermal neutron flux of 5×10^7. Its activity at 100 kev was followed from three to six days after irradiation. The procedure is to set the window of the differential pulse height analyzer and run a curve of activity vs bias until the peak is found. The bias is then set at this value and a count made. A least-mean-square fit of the data gave 2.316 ± 0.016 days for the half-life. Wahl and Seaborg report 2.33 days for this half-life (*5*).

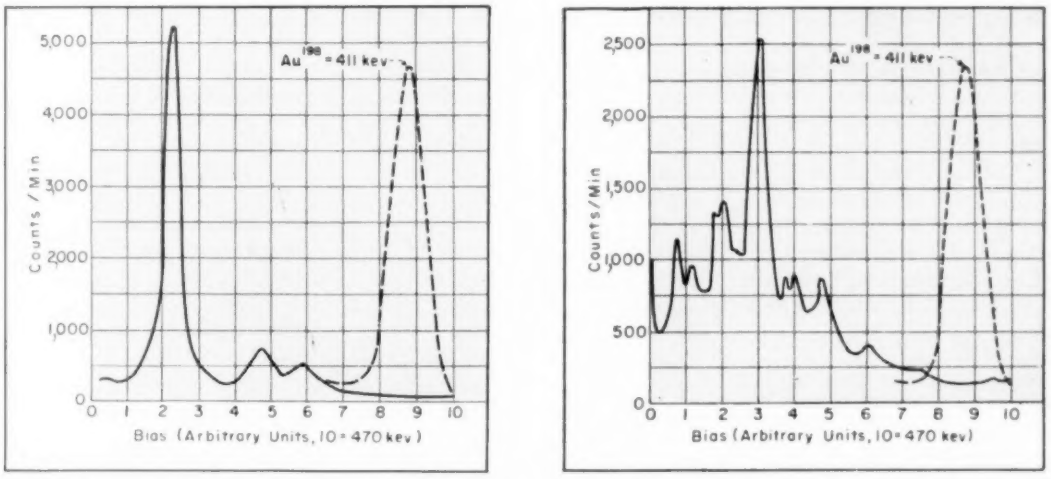
Also shown in the graph below is a spectral curve of an enriched uranium oxide impregnated plastic foil that was irradiated at the same time in the same flux used to obtain the data with the natural uranium pin. This curve was also taken three days after irradiation so that the results of both spectra are directly comparable. It is worth noting that although many peaks occur from various fission products, none of them are at the energy of the 100-kev line of the Np^{239} decay. From the geometries of the two foils (natural and enriched) and the relative amounts of U^{235} in each, calculations show that the fission-product contribution is less than 1% when the spectrometer is set on the 100-kev line from natural uranium three days after irradiation. That there is no appreciable interference from fission products is further borne out by the experiment that measured the expected half-life to a high precision.

* * *

The authors would like to express their deep appreciation to George F. O'Neill and Robert K. Swank whose illuminating discussions greatly aided the work reported here.

BIBLIOGRAPHY

1. R. Hofstadter, NUCLEONICS **4**, No. 4, 2; No. 5, 29 (1949)
2. K. Way, *et al.*, Circular 499, pp. 266 and 268 (National Bureau of Standards, U. S. Department of Commerce, Washington, D. C., 1950)
3. H. Slätis, *Nature* **160**, 579 (1947)
4. N. Feather, *Nature* **160**, 749 (1947)
5. A. C. Wahl, G. T. Seaborg, CN-266 (unpublished Manhattan District report)



SPECTRAL CURVES taken 3 days after irradiation; Au^{198} given for calibration. At left, Np^{239} activity obtained with natural-uranium pin; fission-activity curve at right taken with enriched uranium oxide impregnated plastic foil

Standardization of Beta-Emitting

Results obtained with these methods at the National Bureau of Standards . . .

TABLE 1—NBS Standardization Methods

	Primary standardization		*Secondary standardization*	
Nuclide	*Counting method*	*Accuracy (%)*	*Counting method*	*Accuracy* (%)*
P^{32}	$4\pi\beta$	±1	$2\pi\beta$ ionization chamber	±0.3
			Formamide counting	±1
I^{131}	$4\pi\beta$	+3	$2\pi\beta$ ionization chamber	±0.3
		−2	$4\pi\gamma$ ionization chamber	±0.5
			Formamide counting	±1
Co^{60}	$4\pi\beta$	+2	$4\pi\gamma$ ionization chamber	±0.5
		−1	Formamide counting	±1
	β-γ coincidence	±1		
	γ-γ coincidence	±1		
C^{14}	CO_2 gas G-M	†	Formamide counting	±0.5
Tl^{204}	$4\pi\beta$	+4	$2\pi\beta$ ionization chamber	±0.3
		−2	Formamide counting	±1
Sr^{90}-Y^{90}	$4\pi\beta$	+2	$2\pi\beta$ ionization chamber	±0.3
		−1	Formamide counting	±1
Au^{198}	$4\pi\beta$	+3	$4\pi\gamma$ ionization chamber	±0.5
		−2	$2\pi\beta$ ionization chamber	±0.5
	β-γ coincidence	±3		

* The standard deviation of the average of a set of measurements is usually $\leq 0.3\%$.
† Accuracy appears to be in doubt by 5–10%.

. . . were compared with measurements made at laboratories in the U. S., Canada, and England to provide more accurate standards

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FOR SEVERAL YEARS one of the major activities of the Radioactivity Section of the National Bureau of Standards has been a program leading to the development and improvement of methods of standardization of the disintegration rates of radioactive substances. This paper describes the methods and techniques thus far developed for both primary and secondary standardization and the chemical techniques involved in the preparation of sources and of standard solutions. Results obtained with such sources by standardizing laboratories in the United States, Canada and England are compared.

The methods currently in use at the National Bureau of Standards for the primary and secondary standardization of P^{32}, I^{131}, Co^{60}, C^{14}, Tl^{204}, Sr^{90}-Y^{90} and Au^{198} are listed in Table 1. The accuracies in the third column represent the limits to which the sources of error studied could affect the primary standardization. In all cases the precision of the primary measurements is a few tenths of one per cent. The asymmetry in the assignment of + and − values for the accuracy of the primary measurements is based on the fact that all corrections to observed counting rates in the 4π counting technique are positive. The precision of secondary standardization is generally better than 0.5% and will be treated later in this article.

Nuclides

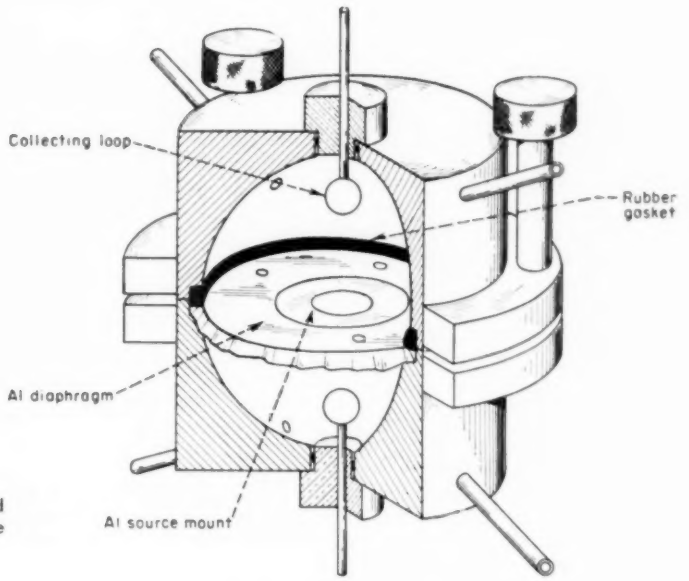

FIG. 1. NBS $4\pi\beta$ counter; counting volume is divided by Al diaphragm, each part having its own collecting wire

PRIMARY STANDARDIZATION METHODS

With the exception of C^{14}, all of the nuclides here reported have been standardized by the 4π proportional counting method described by Seliger and Cavallo (*1*) and further refined by Mann and Seliger (*2*).

4π Counting

The NBS 4π counter is shown in Fig. 1. The counter consists of two halves, each with its own collecting loop. The counting volume is divided into two halves by a thin aluminum diaphragm, so that each hemisphere acts as a separate counter. When a source is mounted on the diaphragm between the two halves, the geometry is essentially 4π. In practice the source is allowed to dry on a thin film, which is then placed over a small hole in the center of the aluminum diaphragm. Methane is used as a flow gas at atmospheric pressure. The counter is operated in the proportional region; high voltage is supplied by a precision high-voltage supply (*3*). The ionization pulses are amplified in nonoverloading linear amplifiers (*4, 5*), which have been found to be ideally suited for proportional counting at high overloads.

The 4π counting method is the most generally applicable method of standardization, since it is independent of the complexity of the decay scheme of the nuclide involved. Cascade gamma radiation only adds to the original beta ionization pulse since it occurs well within the resolving time of the proportional counter and amplifier combination. In evaluating the 4π counting method of primary standardization, three separate factors are considered: (a) the counting efficiency, (b) the absorption in the mounting film and (c) the self-absorption in the source.

Counting efficiency. The term "counting efficiency" refers only to the probability that a beta particle, emitted into the sensitive volume of the counter, will be detected as a pulse above the noise level of the amplifier output. The capacity of the 4π counter, together with its lead-in wires, determines the amplitude of the voltage pulse produced by an ionizing event inside the counter. From estimates of the capacity and of the gas amplification, one is able to deduce the minimum amount of primary ionization necessary for an ionizing event to be detected by the amplifier. Approximately six ion pairs are required, corresponding to a low-energy cut-off of 200 ev. In the energy spectra of the nuclides here considered, the relative number of electrons with energies below 200 ev is negligible. Even in the case of C^{14} (E_{max} = 155 kev), only 0.2% of the beta particles emitted have energies less than 200 electron volts. Therefore, it is assumed that the low-energy cut-off introduces negligible error into the 4π counter standardization of P^{32}, I^{131}, Co^{60}, Tl^{204}, Sr^{90}-Y^{90} and Au^{198}.

A more serious loss in counting efficiency is caused by the use of a nonconducting film as a source mount. Since the positively charged collecting wires are not completely shielded from each other, there exists between them a region of low collecting field. In this region, which contains the source, free electrons move slowly and recombination can occur with high probability. Thus beta particles may not be detected unless they have sufficient energy to ionize outside of this low-field region.

"Mirror-image" measurements (*2*) can correct for the efficiency loss in the case of the nonconducting films. However, the use of conducting films as source mounts has eliminated the low-field region completely. The counting efficiency is now better than 99% and is assumed to be 100%.

Absorption in the mounting film. If the effect of backscattering from the thin film is neglected, τ, the fractional absorption in the mounting film (*1*) is given by

$$\tau = (N_t - N_b)/(N_{tb} - N_b) \quad (1)$$

where N_t = counting rate in the top half of the 4π counter, N_b = counting rate in the bottom half of the 4π counter, and N_{tb} = counting rate with top and bottom halves connected in parallel.

A more exact expression, using sandwiched sources and neglecting only sec-

ond-order backscattering effects (*2*), is given by

$$\frac{\tau}{2} = \frac{N_{ib} - N_{ib}'}{2N_{ib} - N_{a}'} \qquad (2)$$

where the primes refer to observed counting rates measured for the sandwiched source. The sandwich method of determining film absorption is also used by R. C. Hawkings (*6*).

In Eqs. 1 and 2, τ is determined from the difference between two large numbers, which are nearly equal. Each of these numbers has an uncertainty of probably 0.5%. Hence, since τ is small, the spread of individual values for τ can be as great as 50%. The average value of τ is therefore applied to all data. The uncertainty due to the correction for absorption in the mounting film is not greater than 0.5%.

Self-absorption in the source. Self-absorption in the source is the limiting factor in the use of the 4π counting method for the standardization of low-energy beta emitters. It can be minimized but never completely eliminated. All other factors being equal, the amount of self-absorption depends on the energy spectrum of the nuclide in question, being greater for the lower-energy beta emitters.

It is necessary to add carrier to a solution of a radionuclide to ensure proper chemical behavior and to prevent appreciable loss of activity by adsorption. The amount of carrier to be added usually depends on the number of unstable nuclei and the chemical affinity of the radioactive salt. In the case of P^{32}, the carrier is a solution of 0.001*M* H_3PO_4. At this concentration, adsorption is negligible and the solid material introduces practically no self-absorption in 4π counter sources. This is due to the fact that there are relatively so few low-energy beta particles emitted by P^{32} (E_{max} = 1.71 Mev). Those that are absorbed in the source represent a very small percentage of the total number emitted.

TABLE 2 Effect of Source Preparation on $4\pi\beta$ Counting

Preparation method	*dps/ml* $\times 10^{-3}$ *(average)*
Evaporated $SrCl_2$, evaporated YCl_3	818.6
Precipitated $SrHPO_4$, evaporated YCl_3	851.9
Precipitated $SrHPO_4$, precipitated $Y(OH)_3$	867.8

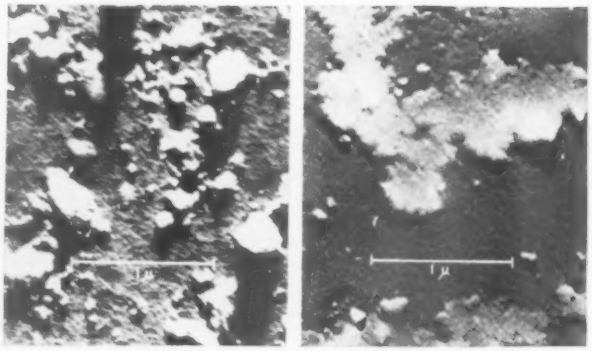

FIG. 2. Electron micrographs of I^{131} source; chromium-shadowed 4:1

However, in the case of Co^{60} (E_{max} = 310 kev), the carrier does introduce self-absorption in 4π counter sources. In addition, the amount of self-absorption depends on the chemical method of source preparation, as illustrated by the results of the following experiment.

A series of 4π counter sources of Co^{60} were prepared by delivering identical aliquots of a master solution containing $CoCl_2$ to thin-film source mounts. All sources were dried completely by evaporation. Then one half of the sources chosen at random were redissolved by the addition of a drop of water and were placed, together with a small beaker of NH_4OH, inside a desiccator. The cobalt precipitated as a complex cobalt-ammonia molecule. Next, all sources were measured in the 4π counter.

The half that had been evaporated to dryness gave results 5–10% lower than the half that had been precipitated with NH_4OH. In addition, the results obtained from the precipitates of the cobalt-ammonia complex had a much smaller standard deviation than the results obtained from the evaporated sources. Besides the lower self-absorption, precipitation had given a more uniform deposit than evaporation.

To show this more directly, autoradiographs were made of all sources. The radiographs of sources prepared by evaporation showed one or two small intense spots along the periphery of the original liquid drop, while radiographs of precipitated sources showed a diffuse darkening over the entire area of the original liquid drop. The $CoCl_2$, upon evaporation of the water, had crystallized out at one or two points. This, coupled with the fact that Co^{60} emits a fairly large number of low-energy beta particles, gave rise to the self-absorption losses observed. The precipitates of the cobalt-ammonia complex, on the other hand, were distributed uniformly over the original area of the liquid drop, thus giving a minimum of self-absorption.

As a further example of the importance of proper source preparation, Table 2 shows results, similar to those of the Co^{60} sources, for the case of Sr^{90}-Y^{90}. The effect of precipitation is shown more strikingly as first the parent and then the daughter is precipitated.

These results are in complete agreement with previous work of the same nature performed with I^{131}. In the experiments with I^{131}, electron micrographs were made of representative areas of precipitates of AgI and KNO_3 formed by adding a drop of $AgNO_3$ solution to a drop of KI solution containing the active iodine. Figure 2 shows 4:1 chromium-shadowed micrographs; the total magnification is 40,000. The precipitated material forms lumps of varying size, which occupy less than half of the total area. Although the lumps are quite small, much smaller than crystals formed upon evaporation, there is a residual self-absorption due to the finite size.

Table 3 summarizes the chemical procedures used for the preparation of sources for 4π counting as well as the estimated self-absorption corrections. The corrections are based on observations of particle sizes made with high-power optical microscopes and electron microscopes. They also take into consideration the energy distributions of the emitted beta particles and the variation of absorption with the atomic numbers

TABLE 3—Source Preparation and Self-Absorption for 4π Counting

Nuclide	*Volume delivered to source mount*	*Preparation procedure*	*Estimated self-absorption correction*
P^{32}	0.05 ml	Dry in air	$0 + 0.5\%$
I^{131}	0.05 ml	Add $AgNO_3$, dry in air	$2 \pm 1\%$
Co^{60}	0.05 ml	Dry, add water, dry in NH_3 atmosphere	$2 \pm 1\%$
Tl^{204}	0.05 ml	Dry, add H_2O_2, dry, add H_2O_2, dry in NH_3 atmosphere	$0 + 1\%$
Sr^{90}-Y^{90}	0.05 ml	Dry, add H_3PO_4, dry, add H_2O, dry in NH_3 atmosphere	$0 + 1\%$
Au^{198}	0.05 ml	Dry in air	$0 + 1\%$

of the constituents of the precipitates. The large uncertainties are due to the wide distribution of lump sizes and to the straggling of electron ranges. It must be emphasized that the corrections given are valid only when self-absorption has been reduced to a minimum.

Coincidence Counting

The coincidence technique presents none of the problems in source preparation observed in the 4π counting technique since the source need only be thin to the γ component of the cascade. In actual practice a scotch tape sandwich of the evaporated source, mounted in a fixed geometry relative to the coincidence counters, is adequate.

β-γ coincidence counting. In the β-γ coincidence measurements on Co^{60} and Au^{198}, anthracene was used as the β crystal and thallium-activated sodium iodide, NaI(Tl), was used as the γ crystal. The anthracene was polished very thin so that γ pulses could be discriminated against in the β channel of the coincidence analyzer. In a similar manner, the acceptance level of the γ channel of the coincidence analyzer was set high to exclude lower-energy scattered radiation. There were no angular correlation corrections required in the β-γ coincidence technique as applied to the Co^{60} and Au^{198} radioisotopes.

γ-γ coincidence counting. In the γ-γ coincidence measurements on Co^{60}, NaI(Tl) was used in both detectors. Again the acceptance level of both channels was set high to exclude the lower-energy scattered radiation. Measurements made at 90 and 180 deg were corrected for angular correlation and for the finite solid angles subtended by the NaI crystals.

In those cases where the decay scheme of a nuclide is a simple β-γ cascade, the coincidence method of primary standardization is more accurate than the 4π counter method. However the decay scheme must be known accurately. Uncertainties in branching ratios or in the knowledge of internal conversion coefficients introduce uncertainties into the measurements regardless of the precision obtainable. As the name implies, the method cannot be used for pure beta emitters such as phosphorus-32, carbon-14, thallium-204 and Sr^{90}-Y^{90}.

Internal Gas-Counting

The standardization of low-energy beta emitters by the 4π counting method is subject to large uncertainties due to self-absorption, even in precipitated sources. The internal gas counting method avoids the difficulties of source preparation by introducing the active material as a part of the filling gas. Manov and Curtiss (*7*) at the National Bureau of Standards applied this method to the standardization of C^{14}. They used an experimental arrangement similar to that of Hawkings, Hunter and Mann (*8–10*) at Chalk River.

A measured volume of Na_2CO_3 solution containing C^{14} was converted quantitatively to CO_2 in an evacuated system. The C^{14}-containing CO_2 was then mixed with accurately known volumes of CS_2 and inert CO_2 to make up the filling mixture. A series of G-M counters were then filled to known pressures with the filling mixture. The observed net counting rates for the G-M counters, related back to the original volume of the Na_2CO_3 solution, gave the disintegration rate per unit volume of the C^{14} solution.

The counters were operated in the Geiger region and it was necessary to use an external quenching circuit with insensitive times of the order of 1,000 μsec.

End effects. To calculate back to the disintegration rate per unit volume of the original C^{14} solution, it was important to know the exact sensitive volume of the G-M counter. Due to end effects, the sensitive length of a G-M counter does not coincide with the cathode length. The effective lengths were determined by a substitution method as follows:

Two counters were constructed from the same diameter tubing so as to have identical cross sections. The lengths were made different and all dimensions were measured to better than 0.05%. The lengths of both counters were several times greater than their diameters and also greater than the range of the most energetic C^{14} beta particle. Under these conditions the end effects were a function only of the cathode diameter. Since the cathode diameters were made equal, the end effects for the two counters were the same. Also since the counters were filled to the same pressure at the same time, the difference in reading between the long and short counter gave the counting rate that would have been observed for an ideal G-M counter with no end effects and whose length was the difference in length between the two counters.

Wall effects. L. Costrell (*11*) has recently made some calculations on the loss of efficiency of G-M counters caused by that small fraction of the disintegration electrons that strike the cathode without producing any primary ionization. This "wall-loss" is inversely proportional to the pressure, the counter diameter and the primary specific ionization.

On the basis of Costrell's qualitative calculations, the 1,280 dps/ml figure obtained by Manov and Curtiss should be revised upward by several percent. However, even larger discrepancies in disintegration rates determined by CO_2-CS_2 counting have been reported by other laboratories (see Table 10). It is felt that further work must be done on the determination of the disintegration rate of the NBS C^{14} ampoule, and therefore the 1,280 dps/ml value should be retained as an arbitrary reference number until a final value has been obtained.

SECONDARY STANDARDIZATION METHODS

Both a $2\pi\beta$ ionization chamber* and a $4\pi\gamma$ ionization chamber (*12*) have been in use for secondary standardization since January 1953. In addition, a method of relative counting of liquid samples of C^{14} using formamide (*13*) is being adapted to the secondary standardization of the other beta emitters.

In all of these methods, a primary standard, prepared by 4π counting, is used to calibrate the counting chambers, which we will now describe in detail.

$2\pi\beta$ Ionization Chamber

The $2\pi\beta$ ionization chamber is shown in Fig. 3. The body is a sphere approximately 6 in. in diameter. At the base of the sphere is a cylindrical shoulder, which slides smoothly over the source mounting ring. The center of the source-mounting ring is recessed to hold reproducibly a 1-in.-diameter disk on which an aliquot of the active solution is evaporated. The length of the $^1/_8$-in.-diameter brass collecting electrode has been adjusted empirically so that a point source of beta rays can be displaced slightly from the center of the source-mounting ring without affecting the observed ionization current. This ensures that there will be no error introduced into the secondary standardization due to off-center drying of solutions delivered to the disks.

Current measurements are made with a Lindemann-Ryerson electrometer in a rate-of-charge null method (*14*). The background current is less than 5×10^{-15} ampere. As an indication of the sensitivity of the secondary chambers, the term "background equivalent activity" (BEA) is especially useful. The BEA is that activity of a radioactive nuclide that produces an ionization current or counting rate equivalent to the background. In the $2\pi\beta$ chamber, the BEA for P^{32} is 30 dps. Table 4 summarizes the BEA values of the secondary standardization chambers for the nuclides here reported.

Sources are standardized by comparison with a Ra D + E reference source, which is placed in the same position in the source mounting ring. The chamber calibration constant K is defined as

$$K = AN/R \qquad (3)$$

where A is the activity per milliliter of the master solution determined by $4\pi\beta$ counting, N is the number of milliliters of master solution comprising the source and R is the ratio of the net ionization current due to the standard source to the net ionization current due to the Ra D + E source. Thus the activity per milliliter of an unknown solution is

$$A' = \frac{KR'}{N'} \qquad (4)$$

where primes refer to measurements made on the unknown solution.

Effect of self-absorption. Ionization-chamber measurements of evaporated sources are less sensitive to self-absorption in the source than 4π counter measurements. In the 4π counting method, all particles have equal weight regardless of the amount of ionization they produce. In an ionization chamber, the effect of a beta particle is directly proportional to the ionization it produces. In the NBS $2\pi\beta$ ionization chamber, the mean geometrical path length corresponds to the range in air of a 50-kev electron; a 50-kev electron produces roughly 50 times more ionization than a 1-kev electron and a 1-Mev electron produces approximately 30 times more ionization than a 1-kev electron. Thus the self-absorption of the low-energy electrons, which can amount to several percent in the 4π counter, is reduced to a second-order effect in the ionization chamber because the higher-energy electrons produce relatively higher ionization. None of the differences due to source preparation observed in 4π counting have been observed with the $2\pi\beta$ ionization chamber.

Precision. Corrections are made for pressure and temperature since the chamber is open to the atmosphere. In a set of readings, the individual standard deviation is usually less than 0.3%. The reproducibility of readings over the past 12 months, as determined with the Ra D + E reference source and 4π counter measurements of P^{32}, is better than 0.5%.

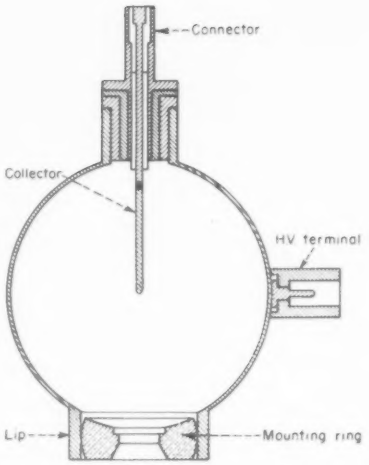

FIG. 3. NBS $2\pi\beta$ ionization chamber

$4\pi\gamma$ Ionization Chamber

In many instances it is desirable to be able to standardize a γ-emitting solution without having to open the sealed ampoule for beta ionization measurements.

Figure 4 shows the NBS $4\pi\gamma$ ionization chamber used for the secondary standardization of γ-emitting nuclides. The chamber is constructed of brass and has a volume of 15 liters. The re-entrant cylinder is separated from the main body of the chamber and is grounded. Sources are inserted into the cylinder and supported at the geometrical center on a Lucite spacer. If a point source of γ-rays is moved vertically through ± 4 cm about the geometric center of the chamber, the response of the chamber remains uniform to $\pm 1\%$. Thus it is possible to standardize solutions of different volumes without being concerned about geometrical effects, provided self-absorption is negligible.

Figure 5 shows the results of measurements made on Co^{60} and I^{131}. In

* We are indebted to Dr. S. Feitelberg of Mt. Sinai hospital for this design.

TABLE 4—Background Equivalent Activity for NBS Secondary Standardization

	BEA (μc)		
Nuclide	$2\pi\beta$ ionization chamber	$4\pi\gamma$ ionization chamber	Formamide counter
P^{32}	0.001		0.001
I^{131}	0.001	1.4	0.001
Co^{60}		0.3	0.001
C^{14}			0.001
Tl^{204}	0.001		0.001
Sr^{90}-Y^{90}	0.001		0.001
Au^{198}	0.001	0.7	

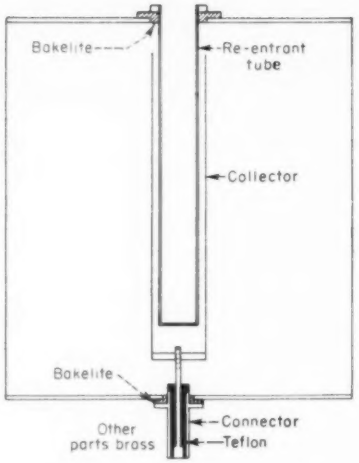

FIG. 4. NBS $4\pi\gamma$ ionization chamber

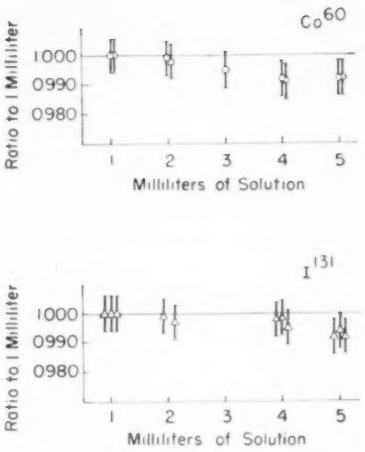

FIG. 5. Effect of increased source volume on NBS $4\pi\gamma$ ionization chamber

these measurements the total activity in an ampoule was kept constant, but the volume was varied from 1 through 5 ml. The ordinate is the ionization current measured, divided by the ionization current measured for 1 ml. Any slight differences can be attributed to increased self-absorption due to the increased volume of solution.

Measurement technique. Current measurements are made with a Lindemann-Ryerson electrometer using a rate-of-charge null method. The background current is less than 4×10^{-14} ampere and the BEA for Co^{60} is 10,000 dps. Standardizations are made with reference to an NBS radium ampoule (in the same manner as the Ra D + E reference source is used in the $2\pi\beta$ ionization chamber). The individual standard deviations are less than 0.3%, and the reproducibility of measurements over the past 12 months has been better than 0.5%.

Formamide Counting

In the formamide counting method, the radioactive material is dissolved in formamide, an organic solvent having a very low vapor pressure compared with water. A typical standardizing procedure is as follows:

A diluting solution of formamide containing 1% carrier is prepared. The solution to be standardized is then diluted by a factor of 100 with the formamide solution to reduce the water concentration to 1%. At this low concentration, the water vapor does not change the counting characteristics of the internal gas counter used. The formamide solution containing the active material is then pipetted into a stainless-steel cell and counted in an internal gas counter, such as the Nuclear Measurements Corp. PC-1. If the volume, and hence the depth of solution to be standardized, is always the same, any effects due to γ-rays will be constant. Thus the formamide method of secondary standardization can also be used for β-emitters that have accompanying γ-rays.

Precision. Measurements made in the PC-1 internal gas counter are quite consistent provided the size and shape of the collecting wire are kept constant. It has been found in the case of P^{32} that changing the diameter of the collecting loop can change the efficiency of the counter. This difficulty has been eliminated by the use of nonoverloading amplifiers in place of the PC-1 amplifier to completely saturate all pulses. The BEA for the formamide counter is less than 0.001 μc for all beta emitters, and the precision is usually better than 0.5%. A more complete report will be published soon (*15*).

PHYSICAL AND CHEMICAL CONSIDERATIONS

Table 5 summarizes the nuclear data of importance in the primary standardization of the nuclides P^{32}, I^{131}, Co^{60}, C^{14}, Tl^{204}, Sr^{90}-Y^{90} and Au^{198}. The table also gives the chemical form in which these standards are issued by NBS.

Phosphorus-32

Jensen and Nichols (*16*) have shown that a 25-day P^{33} activity is present in pile-produced P^{32}. They estimate that P^{33} is initially present as 1% of the total activity. Since P^{32} decays more rapidly than P^{33}, this ratio increases with time. In addition, since the P^{33} beta particle has an E_{max} of only 250 kev, the measured half-life depends not only upon the time elapsed since removal from the pile, but upon the method of measurement. If the P^{33} beta particles are completely absorbed by a filter, the activity measured is due only to P^{32}, and therefore a half-life closer to 14.3 days (*17*) should be measured. If this is not the case, it is possible to obtain values as high as 14.59 days (*18*).

Since most outside laboratories use G-M counters in their routine P^{32} analysis, it was thought advisable to measure the half-life of pile-produced P^{32} with an end-window G-M tube in a standard geometry. The mean of several different solutions of P^{32} received from ORNL gave 14.4 days as the effective half-life.

Iodine-131

It is necessary to precipitate the iodide ion as AgI to prevent loss of activity from a source due to evaporation of the iodine. Excess silver ions are added in the form of a drop of $AgNO_3$ solution.

Approximately 1% of I^{131} decays to the 12-day (*19*) isomeric state of Xe^{131}. Therefore, to measure the true half-life of I^{131}, sufficient filtering was used surrounding the I^{131} sources to render negligible the effect of the 160-kev Xe^{131} γ-ray compared with the 638-kev γ-ray. A half-life of 8.075 $\pm$ 0.022 days (*20*) was measured, in agreement with the values of 8.06 $\pm$ 0.02 days and 8.05 $\pm$ 0.01 days found respectively by Lockett and Thomas (*21*) and Bartholomew *et al.* (*22*).

Cobalt-60

In the $4\pi\beta$ primary standardization of Co^{60}, a solution of high specific activity was used. The present Co^{60} solution standards were standardized by comparison with this NBS primary Co^{60} standard solution in the $4\pi\gamma$ ionization chamber. Due to the large amount of solids as shown in Table 5,

TABLE 5—Pertinent Nuclear Data and Chemical Form of NBS β-Ray Solution Standards

	Nuclear data				*Chemical data*			
Nuclide	*Half-life*	*β-ray E_{max} (Mev)*	*γ-ray (Mev)*	*Comments*	*Ionic form*	*Carrier solution*	*Nominal activity furnished (dps/ml)*	*Approx. inactive to active ion ratio*
P^{32}	14.4 days*	1.718	None	Decay corrections masked by the relative growth of 25-day P^{33}	$[PO_4]^{=}$	0.098 gm/l H_3PO_4 in H_2O	10^5	3×10^6
I^{131}	8.075 days (*30*)	0.600 (89.4%) 0.335 (7.7%) 0.250 (2.3%) 0.810 (0.6%)	0.720 0.638 0.364 0.284 0.080 0.160	Approximately 1% of I^{131} decays to a 12-day isomeric state of Xe^{131}, which has a highly converted nuclear γ-ray	I^-	0.020 gm/l LiOH, 0.020 gm/l Na_2SO_3, 0.050 gm/l KI, in H_2O	10^5	2×10^6
Co^{60}	5.2 ± 0.1 yr†	0.319	1.17 1.33	Low beta energy. Self-absorption in $4\pi\beta$ counting	Co^{++}	2.2 gm/l $CoCl_2$ in 0.1 *N* HCl	10^5	2×10^6
C^{14}	5,356 yr‡	0.155	None	Low beta energy	$[CO_3]^{=}$	10.621 gm/l Na_2CO_3, 0.120 gm/l NaOH, in H_2O	1,280	2×10^6
Tl^{204}	4.0 yr (*28*)	0.85	None	Uncertain e^- capture branching ratio; half-life is uncertain	Tl^+	0.001 gm/l $TlNO_3$, 0.16 gm/l $NH_2OH \cdot \frac{1}{2}H_2SO_4$, in 1*N* HNO_3	10^4	1,700
Sr^{90}-Y^{90}	19.9 yr (*29*) 61 hr	0.54 Sr^{90} 2.24 Y^{90}	None None		Sr^{++} Y^{+++}	0.0269 gm/l $SrCl_2 \cdot 6H_2O$, 0.0218 gm/l $YCl_3 \cdot H_2O$, in 1*N* HCl	10^4	9×10^3 3×10^7
Au^{198}	2.698 days¶	0.97	0.411	Possible contamination by 3.3-day Au^{199}	$[Au(CN)_4]^-$	H_2O	10^5	9×10^6

* Mean of several ORNL shipments determined at the National Bureau of Standards by G-M counters.
† Determined at NBS as a result of two primary standardizations spaced 5 years apart.
‡ Arbitrarily accepted value until further work is done.
¶ Determined at NBS as consequence of Au^{198} international comparison. Measurements made in $4\pi\gamma$ ionization chamber.

TABLE 6—Intercomparisons of NBS P^{32} Solution Standards[a]

	United States			*Canada*	*England*				
	NBS (H. H. Seliger)	*ORNL (W. Lyon, E. I. Wyatt, S. A. Reynolds)*	*Columbia University (G. Failla, W. Gross)*	*AECL (R. C. Hawkings)*	*RRU (L. H. Gray, E. W. Emery[b])*	*RRU (N. Veall[c])*	*NPL (W. E. Perry)*	*AERE (J. L. Putman, D. B. Smith, R. A. Allen)*	*RCH (E. H. Belcher, N. G. Trott)*
Zero date (0800)	*$4\pi\beta$ counter*	*defined solid angle*	*emission current*	*$4\pi\beta$ counter*	*absolute β ionization chamber*	*$4\pi\beta$ counter*	*$4\pi\beta$ counter*	*$4\pi\beta$ counter*	*4π liquid scintillator*
Feb. 27, '50	327	317		322					
Sept. 14, '50	240	235	241[d]	243	229				
Mar. 20, '51	633	631		645	617				
	18,600	18,600							
Sept. 1, '51	383			386	374	391			
Mar. 31, '52	246	249[e],245	248[f]	247	243	255			
Sept. 1, '52	489	488		497					
Mar. 1, '53	249	245		249			249		
Mar. 10, '53	161			161	152	160	159[g,h]	165	161
May 4, '53	12,100		11,860						
Sept. 8, '53	114	114[e] 111				114	115.6[h] 114.2[g]	114	

[a] Results given in dps/ml × 10^{-3} as of 0800 on zero date.
[b] Now at Manchester University.
[c] Now at Guy's Hospital.
[d] Based on reported value of 1.06 mc/gm as compared with NBS value of 1.05 mc/gm.
[e] A. R. Brosi and B. H. Ketelle, $4\pi\beta$ counter.
[f] Dilution factor 50:1.
[g] 4π G-M β counter; no correction for foil and self-absorption.
[h] 4π proportional counter; no correction for foil and self-absorption.
[i] W. Lyon, $4\pi\beta$ counting.
[k] Defined solid angle referred to 4π.

the standards are not suitable for $4\pi\beta$ counting. Hence they should be used only as γ-ray standards of Co^{60}. Beta-ray solution standards of Co^{60} will be made available in the near future.

There still is apparently a large uncertainty in the measured half-life of Co^{60}. Half-lives from 4.95 yr (*21*) to 5.3 yr (*23*) have been reported. Standards of Co^{60} prepared in 1947 have been compared with the present Co^{60} primary standards in the NBS $4\pi\gamma$ ionization chamber. Since the accuracy of the 1947 standardization was only $\pm 2\%$, it is not yet possible to choose between 5.1 yr and 5.2 yr. However, the 4.95-yr value almost certainly may be ruled out. Recently Kastner and Whyte (*24*) reported a value of 5.21 $\pm$ 0.04 yr.

Thallium-204

It has been reported that thallium solutions in weak acid are not stable, leading to losses of activity by adsorption and precipitation. We have found that the NBS thallium solution, consisting of $TlNO_3$ in 1*N* HNO_3, has remained stable over the past six months. As an additional safety factor, hydroxylamine sulfate (*25*) is added to the NBS β-ray solution standards of Tl^{204}. This additional solid material can be removed from sources prepared for 4π counting by the addition of H_2O_2 to the evaporated deposit.

The K-capture branching ratio in Tl^{204} is still uncertain. Branching ratios of 1.5% (*26*) and 3% (*27*) have been reported. Since the efficiency of the $4\pi\beta$ counter is not 100% for Hg X-rays, the branching introduces an uncertainty into the measurement.

The half-life of Tl^{204} has been reported as 2.7 yr (*21*) and, more recently, as 4.0 yr (*28*). It will be necessary to restandardize the Tl^{204} ampoules every six months until the half-life is definitely established.

Carbon-14

No measurable adsorption effects have been noticed for the NBS C^{14} solution standards over a period of 6 months from the original date of preparation. Ampoules selected at random were measured in a CO_2 ionization chamber at the rate of one ampoule per week. The measured ionization current in all cases fell within $\pm 0.5\%$ of the average.

Strontium-90-Yttrium-90

The short-lived Y^{90} daughter, with a half-life of 61 hr, grows into equilibrium with a freshly separated Sr^{90}

Research Establishments

Canada

AECL—Atomic Energy of Canada Ltd., Chalk River, Ontario
NRC—National Research Council of Canada, Ottawa

England

AERE—Atomic Energy Research Establishment, Harwell
MRC—Medical Research Council
NPL—National Physical Laboratory, Teddington, Middlesex
RCH—Royal Cancer Hospital
RRU—Radiotherapeutic Research Unit, Hammersmith Hospital, London

United States

ANL—Argonne National Laboratory, Chicago, Ill.
BNL—Brookhaven National Laboratory, Upton, N. Y.
Columbia University, New York, N. Y.
MIT—Massachusetts Institute of Technology, Cambridge, Mass.
NBS—National Bureau of Standards, Washington, D. C.
ORNL—Oak Ridge National Laboratory, Oak Ridge, Tenn.
Sloan-Kettering—Sloan-Kettering Institute for Cancer Research, New York, N. Y.

TABLE 7—Intercomparisons of NBS I^{131} Solution Standards[a]

	United States		*Canada*	*England*					
	NBS (H. H. Seliger)	*ORNL (A. R. Brosi, B. H. Ketelle, S. A. Reynolds)*	*AECL (R. C. Hawkings)*	*RRU (L. H. Gray, E. W. Emery)*			*RRU (N. Veall)*	*NPL (W. E. Perry)*	*AERE (J. L. Putman, D. B. Smith, R. A. Allen)*
				absolute γ-ionization chamber[b]					
Zero date (0800)	*$4\pi\beta$ counter*	*β-γ coincidence*	*$4\pi\beta$ counter*	*k = 2.346*	*k = 2.25*	*k = 2.29[c]*	*$4\pi\beta$ counter*	*$4\pi\beta$ counter*	*$4\pi\beta$ counter*
Dec. 13, '49	250			248		254			
June 8, '50	299		304	300		306			
Jan. 15, '51	193	204	200	196		200			
June 7, '51	243	246	254	246		251	261		
Jan. 14, '52	180		182			178	184		
Mar. 15, '52	2,580	2,650	2,687			2,610	2,690		
June 3, '52	271	267	272		261	257	264		
Jan. 15, '53	251[e]	245	240		236	236	244	251[d] 239[f]	243[f]
June 1, '53	94.8[e]	93.5	89.5			91.9	95.0	90.8[f]	91.2[f]

[a] Results given in dps/ml $\times 10^{-3}$ as of 0800 on zero date.

[b] Calibration constant k of ionization chamber depends on exact knowledge of decay scheme.

[c] Based on presently accepted decay scheme.

[d] 4π G-M β counter; foil absorption correction 2.9%. No correction for self-absorption.

[e] Includes 2% self-absorption correction not previously applied.

[f] 4π proportional counter. Foil correction 2.2%; no correction for self-absorption.

TABLE 8—Intercomparison of NBS Co^{60} Solution Standards[a]

	United States				*Canada*	*England*							
	NBS (H. H. Seliger)	*NBS (Seliger)*	*NBS (R. W. Hayward)*	*NBS (Hayward)*	*AECL (R. C. Hawkings)*	*RRU (L. H. Gray, E. W. Emery)*	*RRU (N. Veall)*	*NPL (W. E. Perry)*	*NPL (Perry)*	*AERE (J. L. Putman, D. B. Smith, R. A. Allen)*	*AERE (Putman, A. M. Wildblood)*	*RCH (W. K. Sinclair)*	*RCH (E. H. Belcher, N. G. Trott)*
Zero date	$4\pi\beta$ *counter*	γ-γ *coinc.*	β-γ *coinc.*	γ-γ *coinc.*	β-γ *coinc.*	*Absolute γ ionization chamber*[b]	$4\pi\beta$ *counter*	$4\pi\beta$ *counter*[c]	β-γ *coinc.*	$4\pi\beta$ *counter*	β-γ *coinc.*	*Absolute γ ionization chamber*[b]	4π *liquid scintillator*
May 7, 1952	0.785[d]	0.792	0.787	0.800	0.790	0.750[e]	0.729[f]	0.763[f,g] 0.729[f,h] 0.795[i] 0.773[k]	0.790[m] 0.802[n]	0.783[o]	0.791	0.753[e]	0.740[p]

[a] Results given in mc/ml as of zero date; measurements made in 1952.

[b] Based on 1 mc $Co^{60} \equiv 13.53$ rh at 1 cm.

[c] The means of several 4π counter sources, prepared and counted at the NBS in the NBS $4\pi\beta$ counter and then sent to and measured by W. E. Perry in the NPL $4\pi\beta$ counter agreed to better than 0.4%.

[d] Includes 2% self-absorption correction.

[e] The close internal consistency of the ionization chamber measurements from RRU, NPL and RCH suggest that possibly the 13.53 rh at 1 cm figure should be changed.

[f] Does not include minimum correction for self-absorption. These measurements were also made before data on effects of precipitation of Co with NH_3 were known.

[g] 4π G-M β counter; foil absorption correction 5.2%.

[h] 4π proportional β counter. Foil absorption correction 4.0%.

[i] 4π G-M β counter; corrected for β efficiency by β-γ coincidence counting.

[k] 4π proportional counter; corrected for β efficiency by β-γ coincidence counting.

[m] Scintillation γ-counter.

[n] G-M γ-counter.

[o] Foil absorption correction 8.2%.

[p] Foil absorption correction 18%. Pulse height correction 8.5%.

TABLE 9—Intercomparison of Two Sets of NBS C^{14} Solution Standards[a]

	United States					*Canada*		
	NBS (G. G. Manov, L. F. Curtiss, F. Mohler)	*ANL (M. G. Inghram)*	*BNL (R. Steele, R. C. Anderson)*	*Sloan-Kettering (G. B. Brown, W. C. Peacock)*	*MIT (G. L. Brownell)*	*AECL (R. C. Hawkings)*	*NRC (H. G. Thode, J. Macnamara)*	*Average of all values reported*
CO, G-M counters (dps/ml)	1,280		1,272		1,410	1,329		1,323
Mass spectrometer[b]	3.87%	3.91%		3.99%			3.70%	3.87%
Half-Life based on average of 3.87% C^{14}	5,356 yr		5,390 yr		4,862 yr	5,159 yr		5,192 yr

[a] G-M counting results given as of June, 1949; measurements made in 1950 and 1951.

[b] Mole per cent C^{14}.

parent in approximately 2 weeks. Yttrium carrier is used in addition to strontium carrier to insure that the Y^{90} activity remains in equilibrium and is not lost to the glassware by adsorption. The $4\pi\beta$ counter standardization gives the combined disintegration rate of the Sr^{90}-Y^{90} combination.

The half-life of Sr^{90} has been reported to be 19.9 yr (*29*).

Gold-198

The procedure used at NBS for preparing Au^{198} standard solutions is similar to that used by the AERE of Harwell. Gold foil received from ORNL is dissolved in aqua regia, dried, and then stabilized with KCN solution to form the complex $KAu(CN)_4$, which can be diluted with H_2O.

The half-lives of two separate Au^{198} solutions measured in the NBS $4\pi\gamma$ ionization chamber were 2.698 ± 0.001 days and 2.699 ± 0.001 days.

INTERCOMPARISONS

The National Bureau of Standards is happy to have the opportunity of participating in intercomparisons with other standardizing laboratories in the United States, Canada and England.

Tables 6–11 summarize the results of all intercomparisons thus far carried out. The tables, with the notes, are self-explanatory. It might be emphasized that the NBS results represent the internal agreement presently obtainable. In some cases, notably Co^{60}, only through close cooperation and intercomparison with the other laboratories have we been able to develop our own techniques to their present level.

Excellent agreement now exists for P^{32} and Co^{60}. Further intercomparisons are to be carried out for I^{131}, C^{14}, Sr^{90} and Au^{198}. It is expected that reports covering their own work in more detail will be issued by the other standardization laboratories.

TABLE 10—Intercomparison of AERE Sr^{90}-Y^{90} Solution Standards[a]

	U. S.	*Canada*	*England*				
	NBS (H. H. Seliger)	*AECL (R. C. Hawkings)*	*RRU (L. H. Gray, E. W. Emery) Reference ion chamber*	*RRU (N. Veall)*	*NPL (W. E. Perry)*	*AERE (Putman, Smith, Allen)*	*RCH (E. H. Belcher, N. G. Trott) 4π liquid scintillator*
Zero date	*4πβ counter*	*4πβ counter*		*4πβ counter*	*4πβ counter*	*4πβ counter*	
Apr. 27, '53	11.44	11.2	12.3[b]	11.2[c]	11.44[d] 11.27[e]	11.12[f] 11.30[f] 11.28[f]	10.9[g]

[a] Results given in μc/gm as of zero date; measurements made in summer, 1953.
[b] Based on previous internal intercomparison.
[c] Foil correction is 1.6%.
[d] 4π G-M β counter.
[e] 4π proportional counter.
[f] Three separate dilutions. No foil correction.
[g] Pulse height correction 2%. Foil correction 3%.

TABLE 11—Intercomparison of AERE Au^{198} Solution Standards[a]

	U. S.	*Canada*	*England*			
	NBS	*AECL*	*MRC*	*NPL*	*AERE*	*RCH*
Method	*(H. H. Seliger, R. W. Hayward)*	*(R. C. Hawkings)*	*(L. H. Gray, E. W. Emery, N. Veall)*	*(W. E. Perry)*	*(Putman, Smith, Allen, Wildblood)*	*(E. H. Belcher, N. G. Trott)*
4π proportional β counter	24.8[b] 24.7[c]	25.4[d]		24.9[e]		24.6[f]
4π G-M β counter				25.2[g]	25.6[h]	
β-γ coincidence	26.2[i]			26.5[k] 25.6[m]	25.6[n]	
Absolute γ ionization chamber			24.3[o]	24.6[o]		25.1[o]
γ reference chamber	25.9[p]		24.2[q] 24.8[r]			
β reference chamber			24.3[s]			

[a] Results given in μc/gm as of 1,500 GMT, May 20, 1953; measurements made in summer, 1953.
[b] AERE ampoule No. 1; precision ±0.2%.
[c] AERE ampoule No. 2; precision ±0.2%; measured in 4πβ counter 9 days subsequent to ampoule No. 1. Half-life of Au^{198} in ampoule No. 2 was measured in 4πγ ionization chamber to be 2.698 ±0.001 days.
[d] Used half-life of 2.697 days; foil absorption correction 0.9%.
[e] Foil correction 1.7%.
[f] 4π liquid scintillation counter; foil correction 3%; pulse height correction 2%.
[g] Foil correction 1.7%.
[h] Mean of several readings of four sources; negligible foil absorption correction.
[i] Based on disintegration scheme of Elliott and Wolfson, *Phys. Rev.* **82,** 333 (1951).
[k] G-M γ-counter; correction for internal conversion 4%.
[m] Scintillation γ-counter; correction for internal conversion 4%.
[n] Mean of equi-γ-sensitive and equi-β-sensitive apparatus; correction for internal conversion 4.3%.
[o] Based on stronger sample from which AERE samples were prepared.
[p] Based on 4πβ counter standardization of a solution of Au^{198} prepared from sample of gold received from ORNL pile. The AERE measurements and the ORNL measurements were made on the same days, yet the 4πγ chamber shows an apparent difference of 4.4%. This is as yet unexplained.
[q] Based on absolute γ ionization standardization of a previous sample.
[r] Based on 4πβ counter standardization of a previous sample.
[s] Based on absolute γ ionization standardization of a previous sample.

BIBLIOGRAPHY

1. H. H. Seliger, L. Cavallo, *J. Research Nat. Bur. Standards* **47,** 41 (1951)
2. W. B. Mann, H. H. Seliger, *J. Research Nat. Bur. Standards* **50,** 197 (1953)
3. L. Costrell, NBS-2330 (1953)
4. W. Bernstein, H. G. Brewer, Jr., W. Rubinson, NUCLEONICS **6,** No. 2, 39 (1950)
5. R. L. Chase, W. A. Higinbotham, *Rev. Sci. Instr.* **23,** 34 (1952)
6. R. C. Hawkings, W. F. Merritt, J. H. Craven, Symposium held at NPL, 1951
7. G. G. Manov, L. F. Curtiss, *J. Research Nat. Bur. Standards* **46,** 328 (1951)
8. R. C. Hawkings, R. F. Hunter, W. B. Mann, *Can. J. Research* **B27,** 555 (1949)
9. W. B. Mann, G. B. Parkinson, *Rev. Sci. Instr.* **20,** 41 (1949)
10. R. F. Hunter, W. B. Mann, W. H. Stevens, *Can. J. Research* **B27,** 545 (1949)
11. L. Costrell, NBS, private communication
12. C. C. Smith, H. H. Seliger, *Rev. Sci. Instr.* **24,** 474 (1953)
13. A. Schwebel, H. S. Isbell, J. V. Karabinos, *Science* **113,** 465 (1951)
14. L. S. Taylor, *Radiology* **17,** 294 (1931)
15. A. Schwebel, H. S. Isbell, J. D. Moyer, J. V. Karabinos, *J. Research Nat. Bur. Standards* (to be published)
16. E. N. Jensen, R. T. Nichols, *Phys. Rev.* **83,** 215 (1951)
17. B. N. Cacciapuoti, *Nuovo Cimento* **15,** 213 (1938); J. G. Bayly, *Can. J. Research* **28A,** 520 (1950)
18. W. K. Sinclair, H. F. Hollaway, *Nature* **167,** 365 (1951)
19. I. Bergstrom, *Phys. Rev.* **80,** 114 (1950)
20. H. H. Seliger, L. Cavallo, S. V. Culpepper, *Phys. Rev.* **90,** 443 (1953)
21. E. E. Lockett, R. H. Thomas, NUCLEONICS **11,** No. 3, 14 (1953)
22. R. M. Bartholomew, F. Brown, R. C. Hawkings, W. F. Merritt, L. Yaffe, private communication
23. J. J. Livingood, G. T. Seaborg, *Phys. Rev.* **60,** 913 (1941)
24. J. Kastner, G. N. Whyte, *Phys. Rev.* **91,** 332 (1953)
25. W. A. Brooksbank, ORNL, private communication
26. E. der Matoesian, A. Smith, *Phys. Rev.* **87,** 193 (1952)
27. L. Lidofsky, P. Machlin, C. S. Wu, *Phys. Rev.* **87,** 391 (1952)
28. G. Harbottle, *Phys. Rev.* **91,** 1234 (1953)
29. R. I. Powers, A. F. Voight, *Phys. Rev.* **79,** 175 (1950)

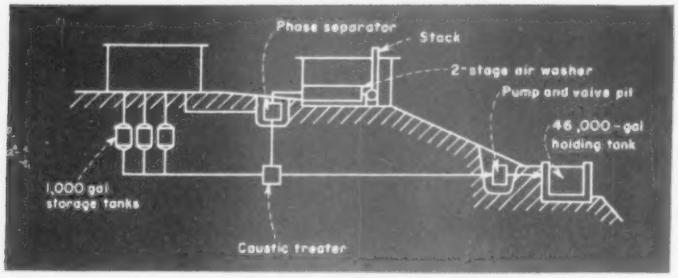

FIG. 1. Layout of waste disposal system

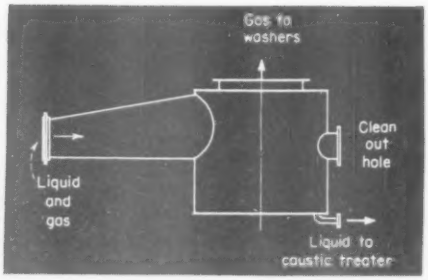

FIG. 2. Phase separator

Design and Performance of a Disposal Plant for Radioactive Wastes

A major problem in the design of waste disposal plants is removal of radioactive particulates from air. An effective air scrubber uses capillary cells and glass-wool pads. Size, density, and velocity of the aerosol affect performance

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IN 1947 DESIGN WAS STARTED at Los Alamos for a new laboratory to process radioactive materials at the kilocurie level. This article describe the effluent plant that was built to handle the resulting wastes.

In this plant air-stream contaminants were to be collected in liquid or slurry form, and waste streams containing alpha emitters were to be isolated from other streams. It was also apparent that high-level gamma-emitting liquid wastes had to be stored until they had decayed to a safe level for further handling. Total capacities required were about 2 gal/min of liquid and about 30,000 ft^3/min of air.

It was concluded that the major design problem involved removal of dust, mist, and fume from large quantities of air, since a review of industrial practice revealed that existing methods did not even approach the needs of atomic energy installations. The only really adequate, tested device was the Type 6 filter paper of the Chemical Warfare Service. However, there were compelling reasons why these filters did not provide a satisfactory answer to the problem. Acid, present in the mist from some operations, would eat holes in the paper; also, frequent replacement of the paper was required, and it was necessary that removal and installation be accomplished by remote control. Since this method of handling the waste air would only create an almost equally difficult problem of handling and disposal of solids in its place, experiments were begun on wet collection methods.

PLANT DESIGN FOR LIQUID WASTES

Provision was made for separate handling of (1) long-lived alpha activity, (2) high-level gamma activity (>10 curies), and (3) low-level gamma activity. As shown schematically in Figs. 1, 2 and 3, low-level liquid and all gaseous wastes are immediately removed from the laboratory building and carried to separators, for separation of the liquid from the gaseous phase, in a common 12-in. stainless-steel (type 316 Cb) line. Waste liquid from the phase separators passes through a caustic treater to control the *p*H at 8–10, and is then pumped to any one of four 46,000-gal concrete storage tanks. A holding period of several months is necessary for the activity to decay to a disposable level.

A remotely-located and shielded valve and pump pit permits transfer from one tank to any other, recycling decayed liquid wastes, and final disposal. Each tank can be treated chemically for recovery or decontamination purposes. Three 1,000-gal buried stainless-steel tanks are provided for storage of liquid wastes containing long-lived or high-level activity.

PLANT DESIGN FOR GASEOUS WASTES

The off-gas from each phase separator (Fig. 2) passes through a separate

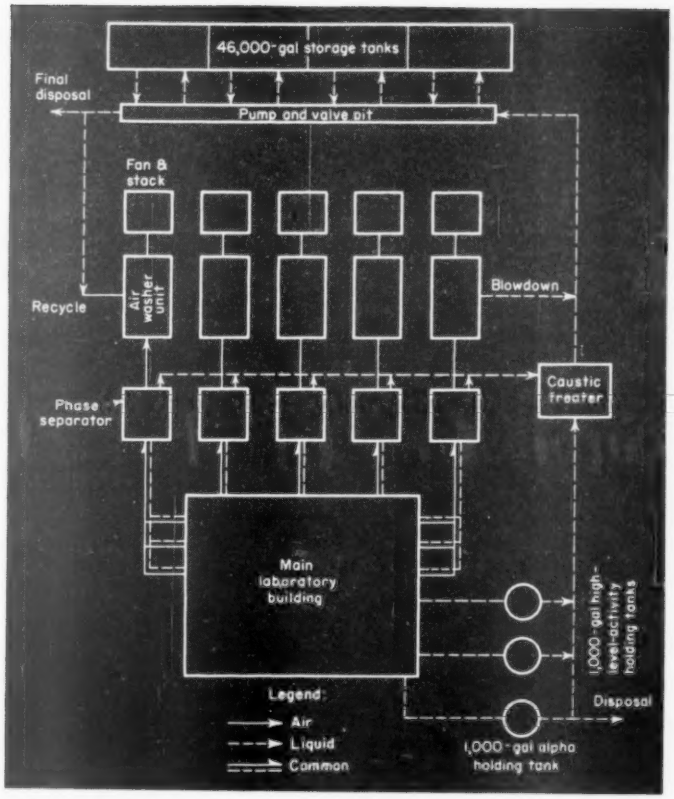


FIG. 3. Flow diagram of waste disposal system

two-stage washer and is discharged from a short stack. The gas-washer installation is shown in Fig. 4.

Design data for this installation were obtained from pilot-scale equipment operated and tested for several years at Los Alamos. The full-scale equipment, consisting of modified capillary air-conditioning units and dry pads, was designed by Charles S. Leopold, Philadelphia, and manufactured by the American Blower Corporation, Detroit, utilizing capillary cells from the Air and Refrigeration Corporation, Atlanta. The gas-washer unit is shown schematically in Fig. 5.

Cells used as roughing filters in the humidification section of the apparatus are of standard manufacture. Each cell consists of a stainless-steel sheet-metal frame, 20 in. high × 20 in. wide × 8 in. deep, packed with glass fibers of 280-micron average diameter to a bulk density of 4.3 lb/ft³. Air enters the unit through the first bank of cells, which are sprayed counter-current to the air flow. After passing through a second bank of cells, in which it is sprayed concurrent to its flow direction, the air passes through a zig-zag entrainment eliminator and then to the fibrous pad. The air passes through the cells at a face velocity of 200 ft/min, and is sprayed with liquid at a rate of 8 gal/min per cell.

The pad, as shown in Fig. 6 (*1*), was packed in random fashion with 240 gm of 10-micron glass-wool fibers and with 4 lb of 250-micron fiber glass used primarily as a support. The pads are 48 in. high × 20 in. wide × 2 in. deep; the air face velocity is 120 ft/min through the pad.

Provision was also made for removal by remote manipulation of each of the washer units. The first unit was constructed of type-347 stainless steel; it was provided with *p*H control. The second unit, fabricated from mild steel, was protected by Coroguard paint on all interior surfaces. Spray heads were installed in various inaccessible areas for periodic decontamination of the washer units.

Since the air enters these units at approximately 50% relative humidity, 0.11 lb of water is lost per 1,000 ft³ of gaseous effluent. All of this loss is supplied by recirculating water from the 46,000-gal storage tanks. Although the water recirculated was usually low in radioactivity, tests showed that even highly contaminated water did not affect the efficiency of the air clean-up.

PERFORMANCE OF AIR-SCRUBBING UNIT

To measure the performance of the air-scrubbing equipment, knowledge was required of the particle-size distribution of the aerosol and of the con-

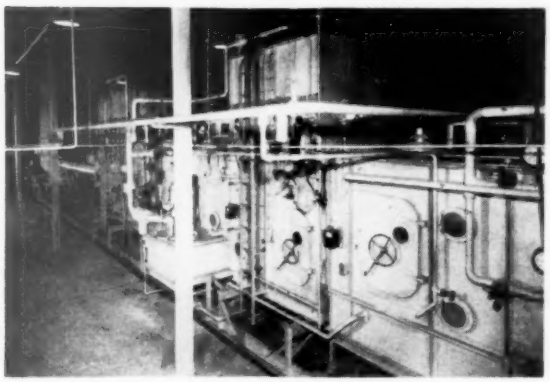
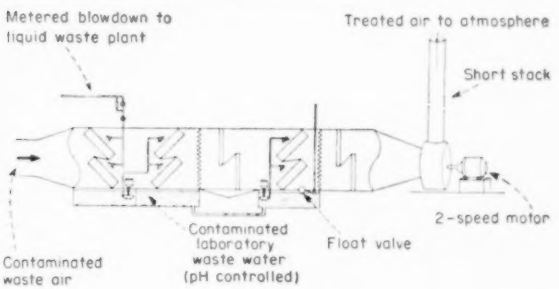


FIG. 4 (left). Gas washer system

FIG. 5 (below). Details of gas washer unit



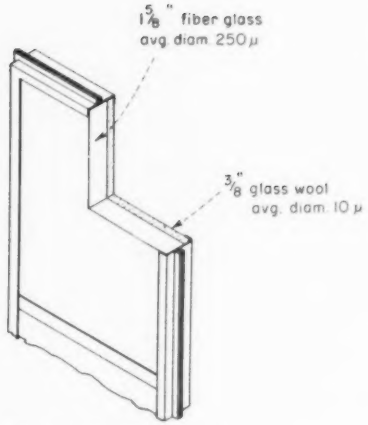


FIG. 6. Glass-wool pad

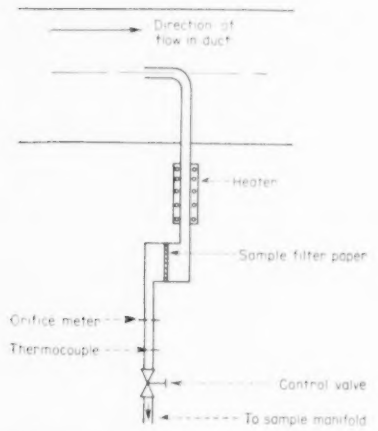


FIG. 7. Details of sample collection unit

Experimental Conditions Used in Studying Variables Affecting Removal of Particulates from Air Streams

Plant	*Capacity* (ft^3/min)	*Range of operating conditions* V (ft/sec)	d_g (μ)	ρ (gm/cm^3)	*Type of aerosol*
One gas-washer-unit					
A	600	3.6	1.2-0.5	7.0	Plant dust Insoluble α-emitter
B	600	4.5	1.2-0.5	7.0	Plant dust Insoluble α-emitter
C	600	5.1	1.2-0.5	7.0	Plant dust Insoluble α-emitter
D	600	2.4	1.2-0.5	7.0	Plant dust Insoluble α-emitter
E	600	3.6	1.4-1.0	3.4	Generated Insoluble α-emitter
F	600	3.6	1.7-1.3	2.3	Generated Soluble β,γ-emitter
G	600	3.6	1.0-0.7	6.4	Generated Insoluble β,γ-emitter
H	3,000	3.6	2.0-1.3	3.0	Plant dust Soluble β,γ-emitter
I	3,000	3.6	2.1-1.4	3.0	Plant dust Soluble β,γ-emitter
J	6,000	6.0	0.6	3.0	Generated Soluble β,γ-emitter
K	6,000	4.5	0.8	3.0	Generated Soluble β,γ-emitter
L	6,000	4.5	0.4	7.0	Plant dust Insoluble α-emitter
Two gas-washer-units in series					
M	600	4.2	1.1-0.8	7.0	Plant dust Insoluble α-emitter
N	3,000	3.6	2.3-1.3	3.0	Plant dust Soluble β,γ-emitter
O	6,000	6.0	0.6	3.0	Generated Soluble β,γ-emitter
P	6,000	4.5	0.8	3.0	Generated Soluble β,γ-emitter

centration of the aerosol entering and leaving the equipment. It was also necessary to study operation of the equipment under various experimental conditions to evaluate their effect.

Sampling and Analyzing

A typical sample-collection unit used in this study is shown in Fig. 7. Sample throats were designed and operated for isokinetic sampling, and sample heaters were used to raise the temperature of the sample to 100° F for the purpose of evaporating entrained water and preventing condensation. The flow rate through the sampler was measured with the orifice meter and was regulated to 4 ft^3/min. This gave a face velocity of 23 ft/min at the Hollingsworth-Vose No. 70 filter paper used as the collecting medium.

The radioactive nature of the aerosols removed by the equipment made it convenient to analyze all samples by alpha, beta, or gamma-ray counting, using standard equipment and techniques. In all cases, the counting rate was divided by the total number of ft^3 of air collected in a sample to give the average cpm/ft^3 of air. From the concentration of radioactive matter thus determined at the various sample points in the equipment, the removal efficiency was calculated.

The filter-paper count analysis was verified in several instances by wet-ashing the filter paper and making a radiochemical assay of the solution. Agreement was good in all cases; only a negligible variation was obtained in the over-all efficiency measured by the various methods.

Particle-size distribution of the aerosols was determined from samples collected with a modified cascade impactor, which was calibrated at the University of Rochester (*2*). These samples were analyzed by alpha, beta, or gamma-ray counting, and in the case of alpha-emitting aerosols, the size distribution was also determined by means of a radioautographic technique (*3*).

Determining the Efficiency

The effectiveness of the described equipment in removing particulate matter from an air stream was found to depend, for the most part, on (1) particle size, (2) particle density, and (3) air velocity (particle velocity). The effect of these variables on performance was studied in three plants, having air capacities of 600, 3,000, and 6,000

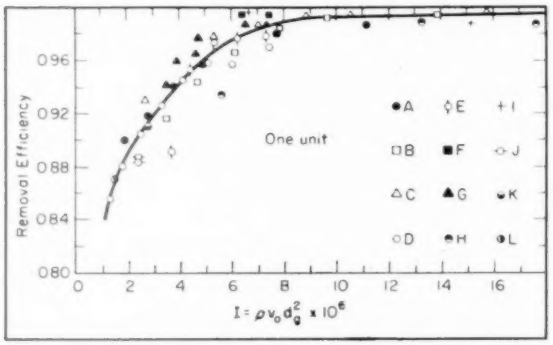


FIG. 8. Performance curve for capillary washer glass-wool-pad systems: one unit

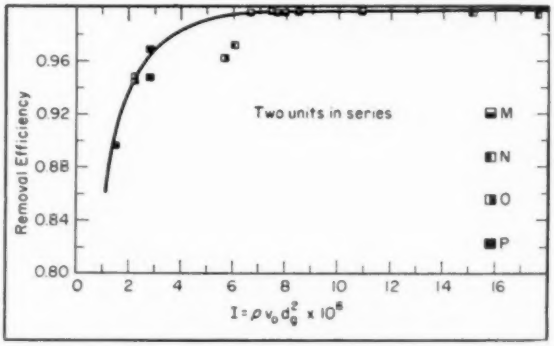


FIG. 9. Performance curve for capillary washer glass-wool-pad systems: two units in series

ft³/min, respectively, as shown in the table. A number of different aerosols were used in the studies; these varied from 2.3 to 7.0 gm/cm³ in density and from 2.3 to 0.4 microns in mass median particle size.

Results from the several hundred test runs made are shown in Figs. 8 and 9. In these figures, removal efficiency is plotted against an impaction parameter, $I = \rho V_0 d_g^2$, where ρ is the density of the particulate matter in gm/cm³, V_0 is the velocity of the air stream in cm/sec, and d_g is the mass median diameter of the particulate matter in cm. Figure 8 illustrates the performance of one gas-washer unit; Fig. 9 shows the performance of two units in series.

By means of these curves, it is possible to approximate closely the performance of a capillary-washer glass-wool pad installation. For example, in the case of an aerosol of density 7.0 gm/cm³, particle size 1.0 micron, and air velocity 3.6 ft/sec, substitution in the impaction parameter equation gives $I = 7.7 \times 10^{-6}$, and the resulting efficiency, as read from Figs. 8 and 9, is 98.8% for one unit and 99.6% for two units.

The effectiveness of the full-scale plant was established in a survey made by the health physics group. The survey showed no increased pollution at seven stations located 500 ft to 2.5 miles from the stack when contaminated air, having activity of about 5×10^5 dpm/liter, was being treated.

Studies of several other variables, such as (1) spray-water rate, (2) aerosol solubility, and (3) condensing conditions, i.e., "fogging," in the capillary washer section, revealed that these were of lesser importance. The efficiency of the units was independent of water rate so long as the spray pattern covered the face area of the capillary cell; the solubility of the aerosol was shown to have very little, if any, effect on the performance of the equipment; and only a slight improvement in removal efficiency was obtainable by "fogging" in the washer section.

Mechanical Aspects

With newly installed equipment, the over-all pressure drop was 2.5 in. of water when operated at design capacity. After two years of continuous operation, the counter-current cells of the first stage were removed because of excessive pressure drop. The pressure drop across the first cell ranged from 0.76 in. of water initially to 2.0 in. of water at the end of three years.

Inspection showed that a heavy "salt" deposit on the upstream face of the cells was responsible for this increase in pressure drop. The deposit on a typical cell is shown in Fig. 10, cell B. This deposit penetrates approximately half-way through the cell packing and results from insufficient flushing and excessive evaporation at the upstream cell face. To alleviate this condition, sprays have been installed to wash continuously the upstream face of the counter-current cells. Cell A in Fig. 10 has been in operation for approximately ten months and shows the beneficial effect of the continuous washdown of the upstream cell face. Since this modification was introduced, the over-all pressure drop has increased at a reasonable rate (approximately 130% per year).

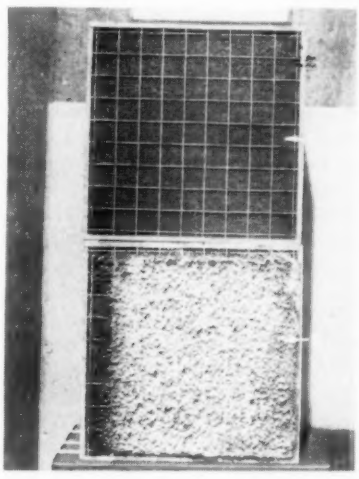


FIG. 10. Capillary cells: A, with upstream sprays; B, without upstream sprays

CONCLUSIONS

Operation of the plant has been quite satisfactory, and the performance has been adequate in every instance. Evaluation of operating data indicates that only the counter-current cells and glass-wool pads of unit No. 1 will require a periodic replacement. Based on the present dust loading (approximately 1 grain per 1,000 ft³), replacement of the counter-current cells and glass-wool pads of unit No. 1 will be necessary in four years. The cells and pads in the second unit appear to have many times the predicted life for unit No. 1, since no appreciable increase in pressure drop has been observed during three years of continuous operation.

BIBLIOGRAPHY

1. R. P. Hammond, J. A. Leary. Air filter, U. S. Patent 2,629,459
2. C. Voegtlin, H. C. Hodge, "Pharmacology and Toxicology of Uranium Compounds," p. 423 (NNES VI-1, Pt 1, McGraw-Hill Book Co., New York, 1949)
3. J. A. Leary. Determination in radioactive aerosols by radioautograph, *Anal. Chem.* **23**, 850 (1951)

FIG. 1. Sample changer and associated equipment

Automatic Sample Changer for Well-Type Scintillation Counter

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The unique problem in designing an automatic sample changer for use with a well-type counter is the transfer of liquid sample vials in glass vials from the storage table to the well of the counter.

The changer described here (Fig. 1) solved the problem by utilizing an electromagnetic pickup and release. It has been in use for seven months, frequently operating 24 hr a day, and has needed a negligible amount of attention.

Components. The commercial equipment used includes a model 161 Nuclear Instrument Co. scaler, an Atomic Instrument Co. model 1248D electrical reset register and a Streeter Amet Co. Ametron printer. The reset register was modified to the extent that an external relay actuated the reset mechanism.

The well-type scintillation counter (H. O. Anger, UCRL-886, 1950) was enclosed in lead rings designed in this laboratory for versatility and ease of repair. The entire counter is surrounded by 1½-in. lead to reduce background.

To accomplish its purpose, the sample changer must lift the lead top, remove the sample counted and return it to the turntable, insert a new sample, lower the lead top, start the preset count, and at the completion of preset count record the time elapsed and then repeat the cycle automatically.

Cycle of operation. In Fig. 2, we can follow this cycle through to completion. With the master switch closed and the sample changer switch on, we have power to the printer and register. While a sample is counting, M.S.8 is held closed by the lead top, activating relay K_6. Upon completion of a preset count, terminals 3 and 4 of the register open, deactivating K_6. This stops the count by shorting out a resistor in the scaler to ground and allows the printer to print the elapsed time. Simultaneously the top motor is energized, which raises the lead cover. This opens M.S.8, and as the top rises it momentarily closes M.S.7, resetting the register. The printer automatically resets after each print and waits for its terminals 7 and 8 to be opened. As the top reaches its maximum height, M.S.6 closes, energizing K_1. This deenergizes the top motor and energizes the turn motor. The turn motor is a 6-rpm Bodine motor that revolves two arms directly opposite each other. The magnets at the end of each arm are also activated at this time. Upon turning through 90 deg, M.S.1 is closed activating K_2 and transferring the power to a 6-rpm Bodine "up-and-down" motor. The latter feeds a scotch yoke and lowers the arms into contact with the sample in the well and also that on the table. As it reaches its lower position, M.S.2 is closed, locking K_3 closed. Upon reaching its starting

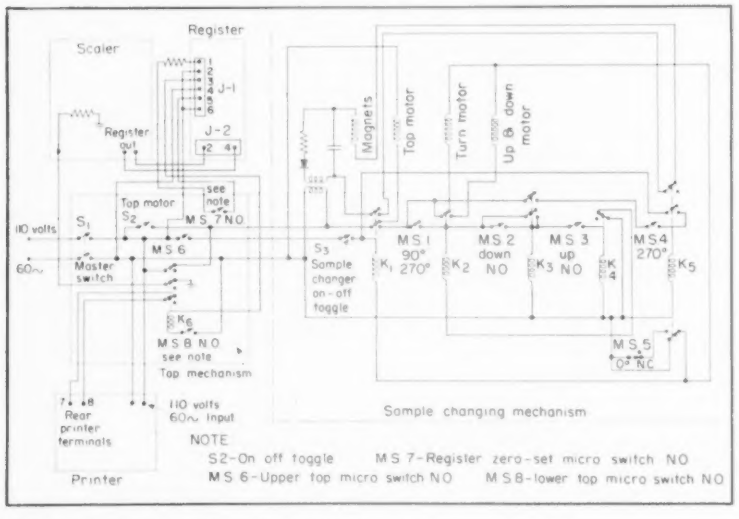

FIG. 2. Circuitry for automatic sample changer

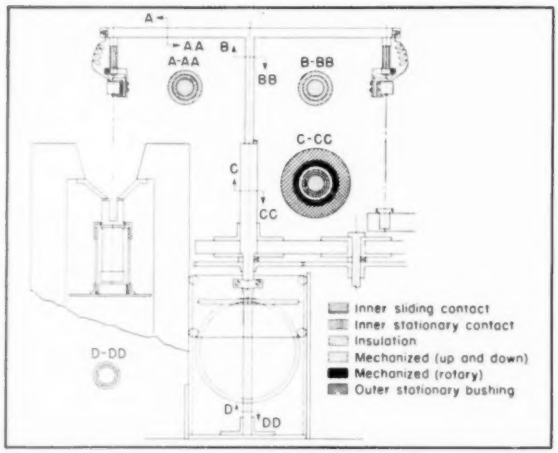

FIG. 3. Lifting mechanism for replacing samples in counter

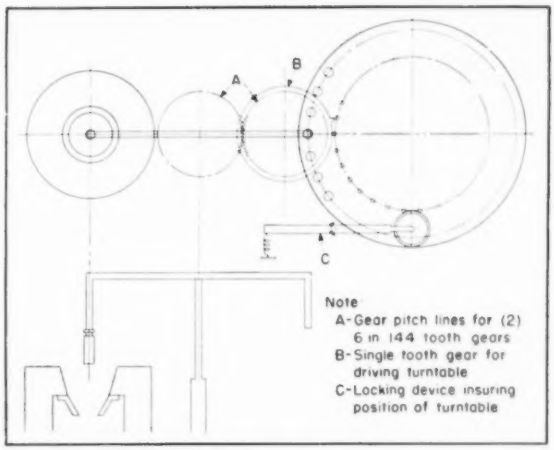

FIG. 4. Turning mechanism for replacing samples

position, M.S.3 closes activating K_4, which releases K_2, K_3 and K_4 and allows the arms to turn through an additional 180 deg. In the 270-deg position, K_2 is energized allowing the arms to lower. Again K_3 is energized, but M.S.4 is closed and K_5 is activated, opening the circuits to the magnets and releasing the samples. K_5 is held closed by holding contacts. As the arm reaches its original position, K_2 is deenergized and the arms continue around to 0 deg, where M.S.5 releases K_1, starting the top motor down. On its way down M.S.7 is momentarily closed, resetting the register for the second time to eliminate any possibility of its not being zeroed. As the top reaches its resting position, M.S.8 is closed, activating K_6, which starts the count, printer and opens the circuit to the top motor.

This sequence is repeated each time a preset count is reached. Also between 270 and 0 deg the table is moved to bring a new sample under the arm on the next cycle. It should be noted that to start the sample changer for the first time, S_2 must be closed momentarily as the register is set to zero and K_6 is energized.

Mechanical construction. The mechanical construction is shown in Figs. 3 and 4. The magnets are supported by bellows to relieve any load on the arms and motor if jamming occurs. The magnets are energized through a contact on the stationary base, pass through the inner stationary contacts to the inner sliding contacts, and through the arms and magnet to ground. In this way the use of rotating leads with their subsequent wear is eliminated. The up-and-down motion is imparted to the arm by a scotch-yoke arrangement. The revolutions of the arm and table are accomplished by gears as shown in Fig. 4. Positioning of the sample is obtained on the table by means of a locking device, *C*, in Fig. 4. This positioning in the well is accomplished by means of a Plexiglas-funnel. The mechanism for raising the lead top cover utilizes a third Bodine motor.

Sample bottles used in the sample changer required a slight modification. Screw-type caps were used on 5-cm^3 vials. A metal disk in each cap enables the magnets to pick them up.

Machining Radioactive Materials

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In many applications of radioisotopes to the study of solid-solid reactions, the active materials may have to be sectioned by machining in a lathe. For example, in the diffusion of metals, the diffusion coefficients can be calculated from the variation of activity with distance.

The usual methods available for machining such radioactive materials have several disadvantages. To guard against the health hazard present during the machining, the operation is often carried out in a hood with strong ventilation. This procedure results in the loss of sample material in the form of fine powder or chips, thereby adding appreciably to the errors of measurement. Besides, the accumulation of radioactive dust in the duct above the hood is not to be commended.

Machining in a stream of water is not satisfactory, since it results in large volumes of liquid that must be decontaminated. The machining operation is awkward because precautions have to be taken against accidentally spraying the water and thus rusting the lathe.

We have tested a simple and effective method of machining radioactive metals. The radioactive sample is placed in the lathe, and its surface is coated with a thin layer of vaseline grease. A small beaker is placed below the sample where it is being cut. The metal removed during the machining sticks to the vaseline and is collected in the beaker. At the end of the machining, the samples are washed with an organic solvent to remove the vaseline, the solution is filtered and the sample on the filter paper is counted in the usual manner to measure its radioactivity.

* * *

We wish to acknowledge support given by the Office of Naval Research.

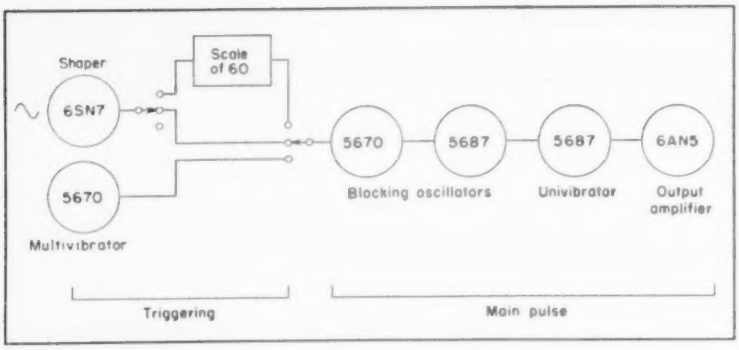

FIG. 1. Elements of fast-pulse generator

Simple, General-Purpose Pulse Generator

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The pulse generator to be described is a compact, low-cost, general-purpose test instrument suitable for numerous applications commonly encountered in nucleonics instrumentation, such as testing and adjustment of linear, transient amplifiers.

The negative output pulse is rectangular in shape and has an amplitude continuously variable from zero to 30 volts at an impedance of 100 ohms. Pulse duration is nominally 1 μsec, with rise and fall times of approximately 0.03 μsec. The main pulse is delayed 0.5 μsec with respect to a positive synchronizing pulse for oscilloscope triggering. This signal is triggered by either internal or external signals in a number of ways, providing great flexibility and convenience in testing or calibration of various types of counters. The pulse repetition rate can be varied from 20 to 3×10^6 cpm.

Description of circuit. Figure 1 shows the relationship between circuit elements.

Pulse-repetition rate is determined by selector switch *S1* (see Fig. 2) with four modes of operation possible. In the first position, the 5670 multivibrator is biased off, and single pulses are produced by momentarily depressing the normally open spring-return switch *S2*. This has been found useful in testing and servicing scaling stages. In position two, the multivibrator is made free running, with a repetition rate of approximately 1,000 pps. In

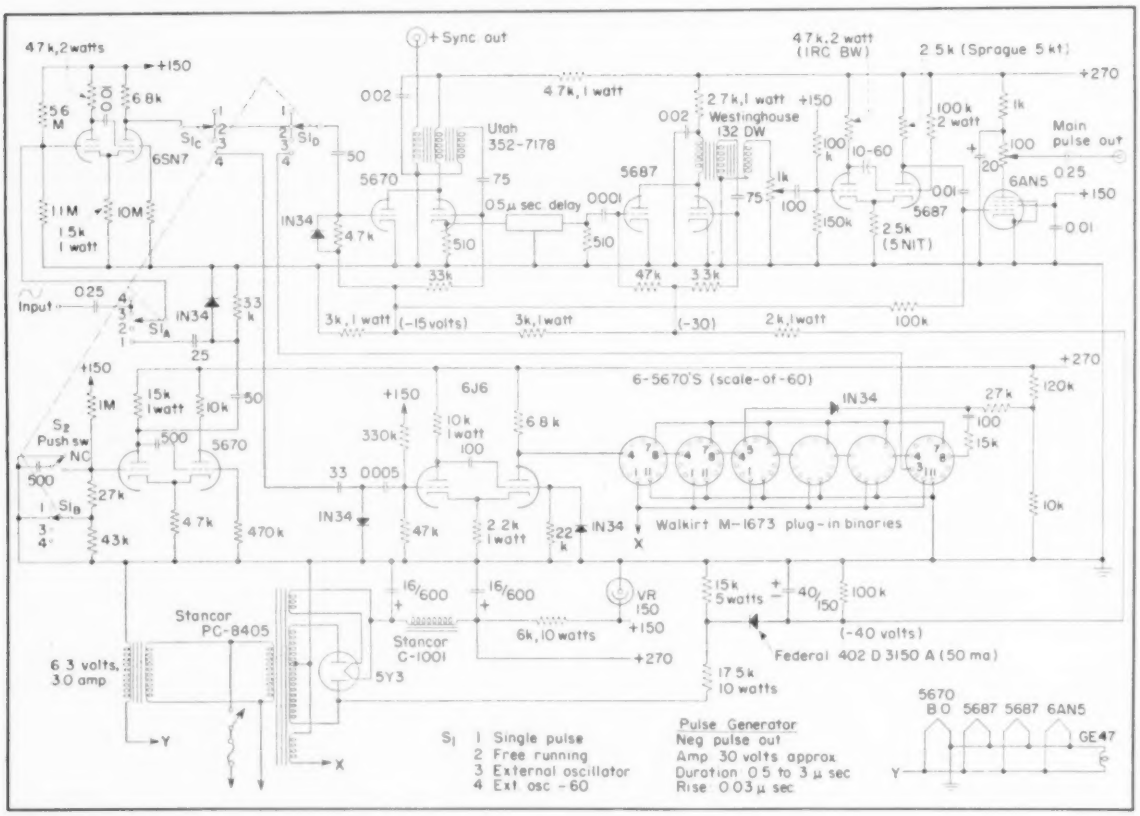

FIG. 2. Generator circuit

the third position, the pulse-repetition rate is determined by an external audio oscillator. A sine-wave input of at least 7 volts amplitude is required to drive the 6SN7 regenerative shaper, at any frequency between 20 cps and 50 kc. Operation at higher rates is erratic, apparently because of transformer limitations in the first blocking oscillator stage.

In position 4, a scale-of-60 is switched in and the maximum input frequency may be increased to about 250 kc. The scale-of-60 is provided for greater convenience in counting-rate meter calibration, since the output pulse-repetition rate, in counts per minute, may then be read directly from the frequency scale of the audio oscillator.*

Scaler design. The scaler is based upon six plug-in binary counters, with appropriate feedback to transpose the basic scale-of-64 to a scale-of-60. The binaries employed† require a negative 75-volt triggering pulse with fall time of 0.2 to 1.0 μsec, and at least 1 μsec duration. Since the differentiated 6SN7 plate signal will not drive the first stage reliably throughout the desired range, a 6J6 fast trigger is employed.

The main output-pulse circuit requires a fast positive trigger. The roughly symmetrical square wave or single pulse (in position 1) produced by the repetition-rate elements described above is differentiated and applied to the grid of the 5670 first blocking oscillator. Conventional parallel triggering is employed (*2*), with a Utah transformer obtained on the surplus market. Any small blocking oscillator transformer may be used, the only requirement being that it be capable of producing a fairly fast pulse, since the rise time of the second blocking oscillator is dependent upon the rate at which it is triggered. A photograph of the positive pulse appearing at the "synch out" terminal is shown in Fig. 3a. Peak amplitude is 130 volts, duration (at 50% peak) 0.6 μsec. The cathode pulse, of essentially the same waveform, is applied to a delay network. In the instrument illustrated, a five-section line was employed (*3*) with Z_0 of 500 ohms and delay per section of 0.1 μsec, using National 50 μhenry chokes and 200 μμf capacitors. Delay cable may be used, although a lumped constant line is satisfactory and may be easier to mount.

The second blocking oscillator supplies a very steep negative-going pulse to help form the leading edge of the square-topped pulse generated in the succeeding stage. Every effort is made to obtain fast rise time. A high-G_m type 5687 tube and Westinghouse 132 DW transformer are used.‡

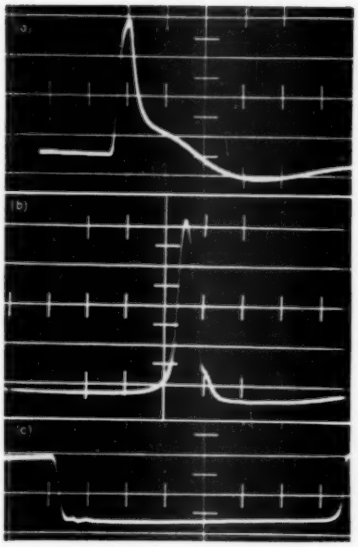

FIG. 3. Available generator waveforms: (a) slow blocking oscillator (synch-out terminal), (b) fast blocking oscillator, (c) 40-volt output pulse; respective sweep speeds are 1.0, 0.2, and 0.1 μsec/div

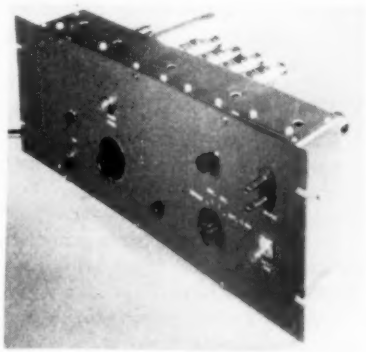

FIG. 4. Dishpan construction assists in compact layout and good heat transfer

Figure 3b is a photograph of the waveform across the 132 DW output winding with 1,000-ohm resistive load. Rise time is of the order of 0.06 μsec.

The following cathode-coupled univibrator stage, also based on the type 5687 tube, generates a rectangular pulse with fairly flat top and symmetrical rise and fall. Wire-wound, inductive resistors are used in the plate circuit to provide some shunt peaking, which further reduces the rise time. Amplitude of the pulse obtained from the normally "on" plate is 70 volts. Pulse duration is determined by the RC coupling constant, and is made variable in the prototype model by means of a screw driver adjustment from the front panel. Circuit values as shown provide a range of 0.5 to 3.0 μsec. This range could be extended by use of a potentiometer instead of the 0.1-megohm fixed resistor from grid to B+.

If this stage is severely overdriven by the fast blocking oscillator, its period will be that of the triggering pulse. Less violent overdriving may also result in waveform deterioration at the top of the leading edge. Hence, a 1,000-ohm potentiometer across the output winding permits the trigger amplitude to be adjusted while observing the output waveform for fastest rise with no overshoot. Adjustment is not critical.

The output waveform, Fig. 3c, is free from overshoot and has only a trace of ringing. This photograph was taken with the output plate directly connected, through a 0.01 mf capacitor, to one of the vertical deflection plates of a Tektronix Model 511A oscilloscope. Pulse duration was reduced to 0.75 μsec to include the whole pulse on a 1-μsec sweep. The measured rise time (10–90%) is 0.024 μsec.

The output pulse is developed across a 100-ohm carbon potentiometer forming the 6AN5 plate load. This tube is normally cut off, and is driven well into the plate-saturation region. Thus the maximum pulse amplitude is determined by the peak current obtainable from this stage. The potentiometer provides a smooth, fairly linear attenuation of pulse amplitude. A correctly terminated 93-ohm output cable (RG-62/U) should be used. External capacitance-compensated resistive dividers are employed for pulses in the millivolt range. One seldom desires both rapid rise time and extremely accu-

* The use of such a scale-of-60, though employed in this and other AEC laboratories for many years, does not seem to have been mentioned in the open literature and forms the main departure from conventional circuitry (*1*).

† Walkirt M-1673 medium-speed binaries were used because they were available. Other types should be equally satisfactory, but may require different triggering and feedback circuits.

‡ Blocking oscillator transformers with ferrite cores are now available commercially, and should be slightly superior.

rate knowledge of pulse amplitude. Emphasis is here placed on the former, within the limitations imposed by receiving-type tubes and conveniently sized power supplies.

Elmore and Sands (*4*) discuss many of the problems associated with the choice of output polarity. To keep this instrument as simple as possible, it was decided to provide only a negative output, with the belief that this should not seriously limit its usefulness.*

The output impedance is low enough to allow one to drive several feet of low-capacitance RG-62/U cable with only slight increase in the rise time. If desired, the plate load could be exactly matched to any of the common cable impedances, with proportionate reduction in amplitude. It should be noted that the cathode follower does not possess low-output impedance for negative pulses. In this case the output impedance is essentially that of the cathode resistor, since the G_m of the tube drops to zero at cutoff. Therefore, a 40-volt negative pulse produced across an output impedance of 100 ohms from a cathode follower requires a continuous current of 400 ma.

Every effort has been made to use reliable components operated in a conservative manner. The "dishpan" type of construction shown in Fig. 4 allows free flow of air past the tubes and power transformer. Ventilation holes are punched in the chassis sides to aid heat transfer from resistors within the totally enclosed space.

All tubes in this instrument are operated as switches, i.e., either cut-off or heavily conducting. In this type of service, cathode interface effects are likely (*5, 6*), and the use of special computer or "premium"-type tubes, although initially more expensive, has proved desirable.

BIBLIOGRAPHY

1. W. P. Jesse. Ratio of 60 pulse generator, MDDC-116 (1946)
2. B. Chance, V. Hughes, E. MacNichol, D. Sayre, F. Williams, "Waveforms," MIT Radiation Laboratory Series, Vol. 19, p. 218 (McGraw-Hill Book Co., New York, 1949)
3. W. Elmore, M. Sands, "Electronics," National Nuclear Energy Series V-1, p. 39 (McGraw-Hill Book Co., New York, 1949)
4. W. Elmore, M. Sands, *loc. cit.*, p. 322 (see especially, comments on the Los Alamos Model 100 pulse generator)
5. A. Fineman, A. Eisenstein, *J. Appl. Phys.* **17**, 663 (1946)
6. H. M. Wagner, *Proc. Nat. Electronic Conf.* **8**, 553 (1952)

* The 100-ohm load could be placed in the cathode lead of the 6AN5, by means of suitable switching, if positive output pulses are also desired. This would inevitably increase the rise time because of added stray capacitance. Also, the waveform would not be as clean because of signal feedthrough by way of grid-cathode capacitance.

Distillation of "Carrier-Free" Iodine-131 Activity

By MILTON KAHN, ARTHUR J. FREEDMAN, and C. G. SHULTZ

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University of New Mexico
Albuquerque, New Mexico

The "carrier-free" iodine-131 solutions available from the Atomic Energy Commission usually contain on the order of 5 mg of total solids per milliliter of solution. Methods presently available for the purification of this material involve the possibility that the resulting solution contains other substances in addition to I^{131} (*1*).

A study of the rate of distillation of carrier-free I^{131} from various aqueous solutions was undertaken to develop a method for the preparation of a pure water solution of iodine activity. Approximately 90% of the activity in a solution of carrier-free I^{131} can be distilled and collected in water according to the procedure described here.

Experimental

Chemically pure or analytical-reagent-grade chemicals were used without further purification. Distilled water available in the laboratory was redistilled from alkaline potassium permanganate in a Pyrex still. Distillations were carried out in a Pyrex apparatus, and magnetic stirring was used to eliminate bumping. Reasonable care was taken to avoid accidental contamination of the solutions with inactive iodine. Samples to be counted were transferred as liquids to calibrated Pyrex test tubes, diluted to a standard height, and placed in a reproducible geometry before a sodium iodide scintillation counter.

A series of experiments was carried out to determine the amount of carrier-free I^{131} activity that could be distilled from acid solutions of various oxidizing agents. The procedure was as follows: Carrier-free I^{131} activity prepared by dilution of material received from the Atomic Energy Commission was added to 200 ml of an acid solution of an oxidizing agent at room temperature. The mixture was boiled and five 5-ml portions of distillate were collected in 10-ml graduated cylinders. Each cylinder contained initially about 2 ml of 0.05*F* sodium sulfite to insure the trapping of the distilled I^{131} activity.

The acid concentration was varied from 0.1*F* to 4*F* in nitric acid, and from 0.1*F* to 12*F* in sulfuric acid. Oxidizing agents used included potassium dichromate, potassium permanganate, ferric nitrate, sodium nitrite, and ceric bisulfate, all at 0.01*F* concentration. Forty percent of the activity distilled

TABLE 1—Effect of Oxidizing Agent on the Distillation from 8*F* H_2SO_4

Oxidizing agent	*Activity in first 5 ml of distillate* (%)	*Total activity distilled* (%)	*Total activity recovered* (%)
0.01*F* $Ce(HSO_4)_4$	83	94	97
0.0016*F* $K_2Cr_2O_7$	38	80	97
0.01*F* $K_2S_2O_8$	16	52	98
0.02*F* $K_2S_2O_8$	22	68	94
0.002*F* $KMnO_4$	40	79	94
0.01*F* $KMnO_4$	24	77	94

TABLE 2—Effect of Ceric Bisulfate on Distillation from 8*F* H_2SO_4

Ceric bisulfate concentration (F)	*Activity in first 5 ml of distillate* (%)	*Total activity distilled* (%)	*Total activity recovered* (%)
0.001	22	77	88
0.005	40	85	89
0.010	83	94	97
0.015	70	95	97
0.020	61	93	96

TABLE 3—Effect of H_2SO_4 Concentration on Distillation from 0.01*F* Ceric Bisulfate

H_2SO_4 *conc.* (F)	*Activity in first 5 ml of distillate* (%)	*Total activity*	
		Distilled (%)	*Recovered* (%)
4	24	39	89
6	62	87	90
8	83	94	97
10	74	92	97

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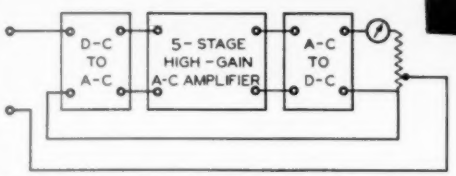

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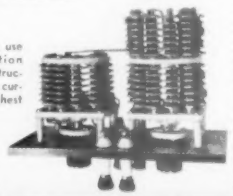

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from 0.01*F* potassium dichromate in 1*F* nitric acid, and 26% from 0.01*F* potassium dichromate in 0.1*F* nitric acid. In other cases, the yields were considerably lower. These data indicate that only small amounts of I^{131} activity can be distilled from acid solutions of common oxidizing agents. It is interesting to note that the over-all recovery of activity was good from all solutions except those containing potassium permanganate. The low recoveries observed in these instances may have been caused by adsorption of activity on the walls of the reaction flask.

In a second series of experiments, prepared active solutions were refluxed, cooled under the tap, and treated with an excess of solid ferrous sulfate. The distillation was then carried out as before. The results of these experiments are collected in Tables 1–3.

It is clear from Table 1 that much better yields of activity were obtained with ceric bisulfate than with any of the other oxidizing agents. The difference between potassium dichromate and ceric bisulfate solutions is in accord with other observations on the chemical behavior of iodine at low concentrations (*2*). The amount of activity that distilled was sensitive to the concentrations of ceric bisulfate and sulfuric acid, as shown in Tables 2 and 3; the best yields were obtained with

TABLE 4—Effect of Iodide Concentration on Distillation*

Iodide conc. (F)	*Collecting soln.*	*Total activity*	
		Distilled (%)	*Recovered* (%)
CF†	5 ml H_2O‡	96	99
CF	5 ml H_2O‡	90	94
CF	5 ml 0.05*F* Na_2SO_3	93	95
CF	10 ml 0.05*F* Na_2SO_3	93	95
10^{-8}	5 ml H_2O‡	90	92
10^{-7}	5 ml H_2O‡	90	93
10^{-6}	5 ml H_2O‡	82	82
10^{-5}	10 ml 0.05*F* Na_2SO_3	97¶	84

* Composition of original solution: 200 ml 8*F* H_2SO_4, 0.01*F* $Ce(HSO_4)_4$. Excess $FeSO_4 7H_2O$ = 10%. Reflux time = 1 hr.

† "Carrier-free."

‡ Approximately 5 ml of 0.05*F* Na_2SO_3 were added to each sample before counting to prevent loss of activity by volatilization.

¶ Thirteen percent of the activity was lost by volatilization during reflux. Percentage recovery in distillate is based on activity present after reflux.

0.01*F* ceric bisulfate in 8*F* sulfuric acid. Variations in the amount of excess ferrous sulfate from 40% to 120% had negligible effect, but reducing the excess to about 10% increased the yield somewhat. Large variations in the time of reflux, above 30 min, did not influence the results. Under the best conditions, most of the activity distilled with the first 5 ml of distillate.

Further similar experiments were carried out to determine whether pure water could be used to collect the activity. In these experiments, one 15-ml portion of distillate was collected in a 25-ml graduated cylinder containing the collecting solution. The data in Table 4 indicate that approximately 90% of the activity can be distilled from 8*F* sulfuric acid containing 0.01*F* ceric bisulfate and carrier-free I^{131} activity, and collected in water. The *p*H of the resulting active solution varied between six and seven.

In some instances inactive iodide was added to the reaction mixture at the beginning of the experiment. It is seen in Table 4 that when the iodide concentration in the solution before distillation was increased to $10^{-6}F$ or greater, an appreciable loss of activity occurred, apparently due to volatilization during reflux. The nature of the reaction between iodide ion and ceric bisulfate is clearly dependent on the iodide ion concentration. These results are consistent with previously reported observations (*2*).

* * *

This article is based on work done under the auspices of the U. S. Atomic Energy Commission and the Los Alamos Scientific Laboratory.

BIBLIOGRAPHY

1. A. W. Kenney, W. T. Spragg, *J. Chem. Soc. Supplements and Index*, 323 (1949)
2. M. Kahn, A. C. Wahl, *J. Chem. Phys.* **21**, 1185 (1953)

TECHNICAL BRIEFS

● **Van de Graaff accelerator** is being tuned up at Hanford primarily for calibration and development of neutron dose meters. Total cost of the 2-Mv 50-μa positive-ion accelerator, building and associated apparatus is $200,000. For meter work, ions will usually be momentum-segregated by magnetic deflection to a target situated over a pit that minimizes neutron bounce-back. For some applications, undeflected heteroenergetic particles will be sent through a 40-ft drift tube to a target within a cubicle enclosed by 4-ft concrete walls.

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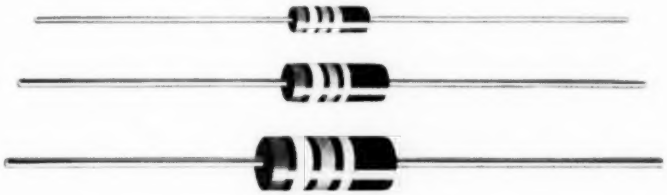

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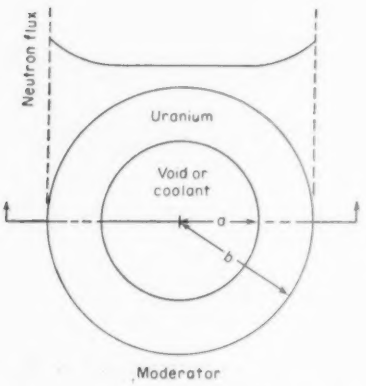


FIG. 1. Geometry and fission source distribution for hollow uranium cylinder

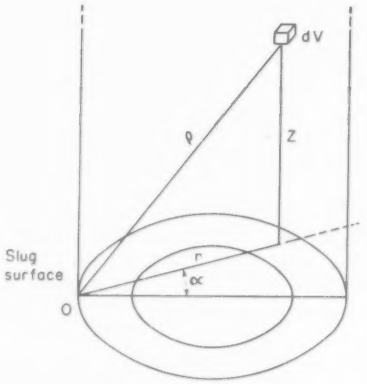


FIG. 2. Geometry for integration of probability for escape, p

How Thermal-Flux Distribution Affects Fast-Fission Factor in U Cylinders

By DONALD E. HOSTETLER, A. C. MENIUS, JR., and RAYMOND L. MURRAY

Department of Physics
North Carolina State College of Agriculture and Engineering
Raleigh, North Carolina

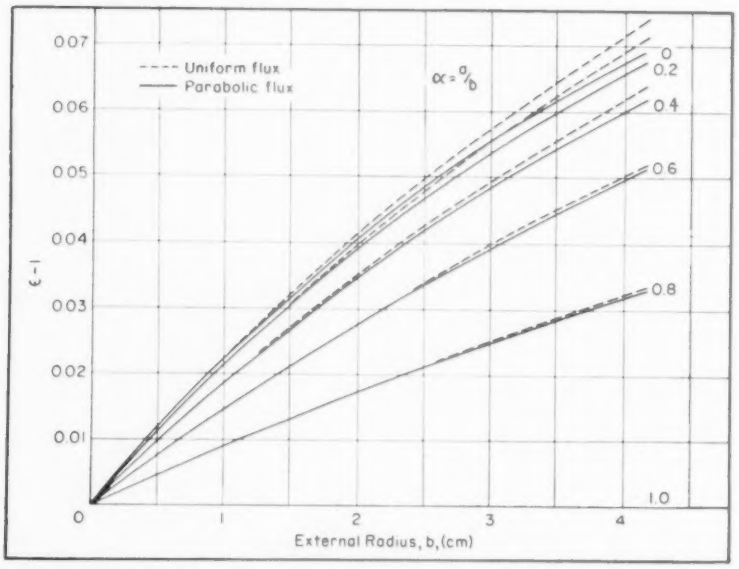


FIG. 3. Comparison for fast fission factors with uniform and parabolic fission sources

Because thermal-neutron flux distribution was assumed uniform, a small error was incurred in a previous calculation (*1*) of the fast-fission factor, ϵ, for natural uranium. Actually, distribution of initial fission-neutron sources is proportional to the position-dependent thermal-neutron flux. The general situation is analyzed here. Values of ϵ are computed for hollow natural-uranium cylinders of a variety of radii, including the special case of a solid slug. Axial flux variations are ignored.

Since the thermal flux is less near the center of the slug, as shown in Fig. 1, the average probability for escape of fast neutrons is slightly higher than for nonvirgin neutrons. If it is assumed that a hollow slug's core is a void or is a coolant with low thermal-neutron-absorption cross section, the thermal-neutron density can be expressed (in terms of modified Bessel functions) by

$$n(r) \sim K_1(\kappa_0 a) I_0(\kappa_0 r) + I_1(\kappa_0 a) K_0(\kappa_0 r)$$

κ_0 is the attenuation coefficient for uranium, r is the radial coordinate in the fuel element, and a is the inside radius of the cylinder.

The probability of either type neutron escaping through the slug surface can be written

$$p = \frac{\int n(\vec{\rho})\, G(\vec{\rho})\, dV}{\int n(\vec{\rho})\, dV}$$

where $\vec{\rho}$ is the vector between the neutron source $n(\vec{\rho})$ and a point on the surface. The attenuation function $G(\vec{\rho})$ includes inverse square spreading and the exponential attenuation *in the metal only*. The evaluation of p consists of the following steps:

1. Establish a convenient geometry for integration. Take origin at slug surface. Adopt source coordinates r, z, and α. Figure 2 shows that r is measured on the diametral plane of the cylinder, z is the coordinate along the cylinder axis, and α is the angle between the diameter through the origin and the vector $\vec{r}$.

2. Approximate thermal-neutron flux and fission-source distribution $n(r,\alpha)$

by a parabola for the case of primary fission neutrons. Take a constant value of n for later-generation neutrons.

3. Integrate directly with respect to r, considering presence of effective voids between neutron source and cylinder surface for some regions of the integration.

4. Expand resultant integrals by Taylor's series in $x = \sin \alpha$ and integrate termwise.

5. Apply Bessel integrals Ki_n (*2*) and numerically integrate to three-significant-figure accuracy in p.

Results. The fast-fission factor was computed by using a modification of the formula of Castle, Ibser, Sacher and Weinberg (*3*)

$$\epsilon - 1 = \frac{(\nu - 1 - \sigma_c/\sigma_f)\,(\sigma_f/\sigma)\,P}{1 - (1/\sigma)\,(\nu\sigma_f + \sigma_e)\,P'}$$

where $P = 1 - p$, and $P' = 1 - p'$ are the probabilities of collision for primary and later generation fast neutrons, respectively. The results of these calculations are shown graphically in Fig. 3.

The difference between the values for uniform fission source, $(\epsilon - 1)_u$, and parabolic fission source, $(\epsilon - 1)_p$, is entirely negligible for small slug diameters and large ratios of inner-to-outer radii.

The discrepancy can become as large as 6% only for solid slugs of 4-cm-radius or greater. A difference of this amount, however, would not be significant in view of other necessary corrections, e.g., for the effect of scattering of neutrons back into the slug by the moderator and for the fact that a finite fraction of the fission spectrum is below the 1-Mev fast-fission threshold of U^{238}. It can be concluded that the results of previous calculations in which P and P' were taken to be equivalent are adequate for heterogeneous reactor calculations.

BIBLIOGRAPHY

1. Raymond L. Murray, A. C. Menius, Jr., NUCLEONICS **11**, No. 4, 21 (1953)
2. W. G. Bickley, *Phil. Mag.* **20**, 343 (1935)
3. H. Castle, H. Ibser, G. Sacher, A. M. Weinberg, CP-644 (1943)

REACTOR FACTS

• **SRE's site** has been selected. North American Aviation's sodium-graphite-reactor experiment will be built by 1956 in the Santa Susana mountains near the firm's rocket test facility.

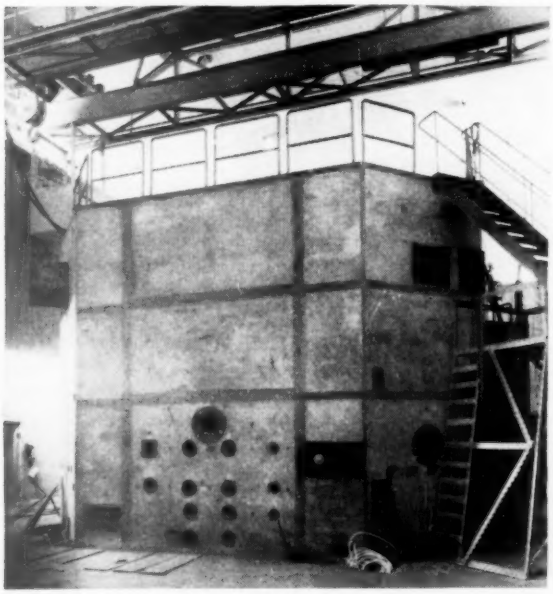
• **Dutch plan** to build $7.4-million experimental reactor. The Dutch government has asked Parliament to spend $2.25-million this year for construction of an experimental reactor. A similar amount will be provided by industry. Balance of the $7.4-million cost will be spent over the next two years.

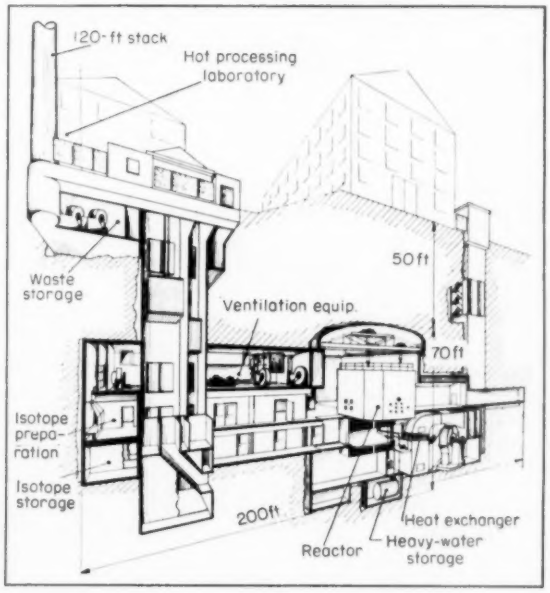
• **Italian experimental** power reactor will involve expenditure of $1.6-million by the Italian government during the next fiscal year. To be built near Milan, the unit will cost a total of $8-million. Studies have been made of D_2O production and uranium metallurgy.

• **MIT research reactor** will be started within the next year. It will cost about $1-million.

• **U. of Michigan's** "swimming-pool" type research reactor's fuel will be supplied by AEC.

• **Argentina announces** power-reactor project. During a one-month official visit by Norway's Gunnar Randers, Argentina's government announced that it was building "without recourse to foreign equipment" an electricity-producing, beryllium-moderated prototype reactor. The country is one of the world's three largest beyllium producers and recently claimed uranium discoveries in the provinces of Mendoza, San Juan, and La Rioja.





SWEDISH HEAVY-WATER REACTOR is nearing completion. Power developed (300 kw) in natural-uranium fuel is removed by a D_2O-to-air heat exchanger. On north face of biological shield (left) can be seen some of the 60 experimental holes. Reactor and supporting facilities (right) are located underground in an area hollowed from solid rock. Three tons of U and 6 tons of D_2O are used; fuel is from state-owned shale plant at Kvartorp. Shale contains only 175–200 gm of U/ton. A 10–20 Mw (electricity) pilot power reactor is scheduled to be built near Stockholm. Britain's Sir John Cockcroft has stated that Sweden's hydroelectric capacity will cover no more than 20 years of further expansion

BOOKS

Magnetic Cooling

By C. G. B. GARRETT (Harvard University Press, Cambridge, and John Wiley and Sons, Inc., New York, 1954, x + 110 pages, $4.50). Reviewed by L. D. ROBERTS, Oak Ridge National Laboratory, Oak Ridge, Tenn.

In his book, "Magnetic Cooling," Dr. Garrett gives a well considered although brief and nonmathematical survey of the properties of matter below 1° K and of the techniques by which these low temperatures are obtained and measured. In the 21 years since the first magnetic cooling experiments were performed, only one other book has been written on this subject, namely, "Magnetism and Very Low Temperatures" by H. B. G. Casimir in 1940. In the latter text, the mathematical foundations of this field are well summarized. Since then relatively little theoretical work specifically applicable to the magnetic cooling process has been done, but many interesting experimental results have been obtained. Dr. Garrett's book reflects this development of the subject, and a good coverage of work through 1950 is given along with some references to publications through 1952.

Low-temperature investigations have been referred to as a small corner of physics and this is true. Yet, such statements may be misleading for there is much in this corner which can be usefully investigated. For example, in the temperature region below one-tenth degree Kelvin, temperatures measured by different methods may differ as much as 30%, even though each of the methods may be internally consistent to a few percent. Similarly measurements of the magnetic properties of many salts as a function of entropy and magnetic field may differ by more than 10% when measured by different but apparently equally reliable and quite precise techniques. Evidently there is yet much to be done to obtain a thorough description and understanding of magnetic salts in this low temperature range.

In addition to its usefulness in the study of paramagnetic salts proper, the magnetic cooling technique is proving to be a valuable tool for the study of other materials below 1° K. At present one may cool substances by heat transfer to about 0.05° K and hold them at these low temperatures for extended periods. An illustration of this technique, which Dr. Garrett cites, is the measurement of the creep velocity of the liquid helium film. Near 1° Kelvin, this velocity is fairly independent of the temperature, and it was thought that this behavior could be extrapolated to absolute zero. Yet when measurements were made below one degree, this velocity was found to increase quite rapidly. In addition to the above, magnetic cooling is finding application, for example, in nuclear alinement and polarization experiments, in the study of metals and in the investigation of liquid He^3 as well as liquid He^4. More generally, the method has a unique usefulness in the study of cooperative phenomena or of any system that has a continuum of or many very closely spaced energy levels.

Before 1940, virtually all of the investigations in this field were performed in a very few laboratories. This was probably due to the rather considerable difficulty of producing and handling the liquid helium which is almost indispensable in magnetic cooling experiments. With the advent of the Collins helium liquefier, the difficulties of obtaining these low temperatures have been much reduced and many laboratories are now entering this field. Thus, Dr. Garrett's book comes at a time to be generally useful to those entering this field as well as to the general reader.

Biological Effects of External X and Gamma Radiation, Part 1

RAYMOND E. ZIRKLE, Editor (McGraw-Hill Book Co., Inc., New York, 1954, xxvi + 530 pages, $7.25). Reviewed by A. C. UPTON, Oak Ridge National Laboratory, Oak Ridge, Tenn.

This volume contains detailed accounts of some of the investigations pursued in the Argonne National Laboratory and in the National Institutes of Health under the Plutonium Project. The studies, executed for the most part during the war and reported in earlier Atomic Energy Commission documents, have been edited and integrated into a series of concise chapters.

The first half of the book is given to detailed reports by E. Lorenz, *et al.*, of the effects of chronic total-body gamma irradiation on mice, guinea pigs, and rabbits. The voluminous data of these life span experiments are well reported; the incorporation within a single volume of the various aspects of these studies, such as effects on longevity, blood picture, pathologic changes, carcinogenesis, and breeding, is a valuable contribution in itself. Likewise, the book is helpful in providing a collation of the studies of Hagen, Jacobson, Sacher, Zirkle, and others on the effects of total-body X-irradiation in rabbits. There are chapters on biochemical and immunological effects of X-irradiation by Barron, Taliaferro, Wattenberg, and associates and a section on radiation protection by Simmons *et al.*

The volume has been carefully edited, in the style of the National Nuclear Energy Series. Chapters are prefaced by brief abstracts and include pertinent references. The tables and graphs are numerous and of good quality; however, the photomicrographs are not consistently well reproduced. Chapter 13, by J. G. Allen and co-workers, is merely an abstract of a paper that appeared in the open literature in 1948 reporting the presence of an anticoagulant in the plasma of irradiated dogs. Inclusion of this abstract as a chapter adds little to the value of the book.

This volume will be helpful to those in the field of radiobiology who wish to refer to the early investigations of the Plutonium Project, since in many instances these studies have been reported hitherto only in documents that did not circulate in the open literature.

Introduction to Experimental Physics

By W. B. FRETTER (Prentice-Hall, Inc., New York, 1954, viii + 349 pages, $9.00). Reviewed by E. CREUTZ, Department of Physics, Carnegie Institute of Technology, Pittsburgh, Pa.

This book meets its end as stated in the preface by giving the reader a vocabulary in experimental physics. Like most sets of lecture notes (from which this book was compiled) it suffers from brevity and the fact that the reader cannot conjure up from cold notes the more complete picture that was presumably made available to those who "took the course."

The techniques described, as admitted in the preface, are largely those of atomic and nuclear physics and primary emphasis is on work done at Berkeley. There is a useful bibliography at the end of each chapter and occasional references throughout the text.

The reviewer finds the chapter on design of experiments the most inter-

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esting. If the entire book could have been written in this vein, referring to the solution of specific critical problems of physics as a basis for describing certain techniques, the whole book would have been more exciting, readable, and valuable. It is clear, however, that it would be very difficult to write such a book.

As unavoidable in any book, there is a gap of about two years between actual practices now current in those laboratories in the most rapidly developing fields, and the latest techniques covered in this book. Therefore, such things as Cerenkov counters, bubble chambers, strong focussing, Herb's metal vapor pump, and plastic scintillation counters are only barely mentioned or left out completely. For less obvious reasons threshold detectors (except C^{11}), radiation effects on materials, high magnetic fields (>15,000 gauss) dee bias, and radiation shields are mentioned hardly at all.

It would have been nice to see at least a short chapter on materials, including such things as greases, waxes, solvents, cements, and solders.

For experienced researchers, many well-known useful facts are noted. Less experienced beginners may be confused by lack of sufficient hints for derivation of formulas and statements. (As examples: The relation between the inhour value and the pile period given on p. 284; and the approximation for the effective field in a magnet to be extended 1.5 times the gap width, and in an electrostatic field 0.6 of the gap width.) Frequently more suggestion of the relative quantitative accuracy of such results would be useful. Other examples: p. 12. "a d-c watt-hour meter is reasonably good"; p. 21, the formula relating tension per unit current in a wire to $B\rho$ neglects the effect of the weight and the stiffness of the wire (except to say it is flexible) and does not stress the importance of the end effects due to method of support. Also no mention is made of the desirable properties of the wire, which would determine the choice of material.

On p. 65, concerning oscillators, the somewhat artful statement is made "when the causes of the parasitics have been analysed an attempt can be made to eliminate them without causing others to start." Although this may be a rather apt description of the exasperated state of mind of the experimenter who attempts to eliminate parasitics, it is not a particularly useful bit of advice.

Some fastidious people will object to the suggestion of painting glyptal on suspicious vacuum joints since this can become a messy bad habit. Although the halide-freon leak detector is described, it is only the flame version. No mention is made of the more modern and more useful General Electric electronic version. Also, no critical discussion is given to the relative sensitivities of leak-hunting methods, the soap suds method and the helium mass spectograph being mentioned side by side.

Good chapters are included on electronic techniques, nuclear emulsions, mass spectroscopy, optical spectroscopy, molecular beams, magnetic resonance, X-ray diffraction, and low temperatures.

This book could well supplement a senior course on Atomic Physics, particularly if the course were taught by an experimental physicist. Placing it in the hands of a theorist would be somewhat dangerous.

BOOKS RECEIVED

Radiation Biology, Vol. 1: High Energy Radiation (Parts I and II), Alexander Hollaender, Editor, McGraw-Hill Book Co., Inc., New York, 1954, ix + 1265 pages, $17.50. (*To be reviewed.*)

Applied Atomic Energy, by K. Fearnside, E. W. Jones, and E. N. Shaw, Philosophical Library, New York, 1954, viii + 156, $4.75. (*To be reviewed.*)

Introduction to Nuclear Engineering, by Richard Stephenson, McGraw-Hill Book Co., Inc., New York, 1954, xii + 387 pages, $8.00. (*To be reviewed.*)

A Text-Book of Radar, 2nd edition, E. G. Bowen, Editor, Cambridge University Press, New York, 1954, xiii + 617 pages, $8.50. In this edition, the last section on applications and the bibliography have been brought up to date. A chapter has been added on recent applications of radar to the physical sciences.

History of American Industrial Science, by Courtney Robert Hall, Library Publishers, New York, 1954, xix + 453 pages, $4.95. This technological history of American industry includes new material obtained from sixty leading American corporations. Fields covered are transportation, communication, chemistry, metallurgy, food, and clothing. The last sections dis-

cuss the present status of these fields in relation to national defense and prospects for future development.

The Fundamentals of X-ray and Radium Physics, by Joseph Selman, Charles C Thomas, Springfield (Ill.), 1954, xii + 340 pages, $8.50. This book is intended for the student X-ray technician. While the theoretical and practical aspects of radiologic physics are well covered, terminology and mathematics are kept to a level understandable to the student technician.

ALSO OF NOTE

Characteristics and Applications of Resistance Strain Gages. This 140-page report, NBS Circular 528, presents the proceedings of a symposium held November, 1951. The papers represent studies conducted by institutions in the United States and abroad. *Government Printing Office, Washington 25, D. C., $1.50.*

Water Pollution Research 1953. This pamphlet describes the work of the Water Pollution Research Laboratory. The work deals with radioactivity contamination of water (effect of conventional water treatment processes on radioisotope wastes), percolating sewage filters, surface water, industrial waste waters, and effects of pollution on fish. *Department of Scientific and Industrial Research, Charles House, 5–11 Regent St., London, S.W.1, England.*

Abnormal and Pathological Plant Growth. This report of the sixth annual symposium sponsored by the Biology Dept., Brookhaven National Laboratory, at Upton, N. Y., contains the full text of the papers and the discussions following each paper. *Office of Technical Services, Department of Commerce, Washington 25, D. C., $2.10.*

An International Bibliography on Atomic Energy. Volume 1, Supplement 2 ("Political, Economic and Social Aspects," $0.30), a bibliography of official publications, United Nations documents, books and articles, covers the period from July 1950 to December 1952. Volume 2, Supplement 2 ("Scientific Aspects," $3.50) lists approximately 8,000 articles, books and pamphlets published in all parts of the world in 1951 and 1952. *International Documents Service, Columbia University Press, 2960 Broadway, New York 27, N. Y.*

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LETTERS

Compatible Plastics for Phosphors

DEAR SIR:

In the January, 1953 issue of NUCLEONICS (p. 44) an article by Muehlhause and Thomas described a neutron-sensitive scintillation mixture composed primarily of equal parts of phenylcyclohexane and methyl borate, with traces of various additives. Attempts to use this mixture in the plastic cells in common use here resulted in softening and general deterioration of the plastic. Tests made by immersing samples of Plexiglas and Lucite, the usual cell materials, in a sample of this mixture for a period of about 7 months resulted in a surface softening of the Lucite, while the Plexiglas was turned into an amorphous rubbery mass. Since mixtures using phenylcyclohexane alone with similar additive composition have given no such trouble, this effect is probably due to permeation of the plastic by the methyl borate. Since Muehlhause and Thomas apparently used cells made exclusively of inorganic materials, they presumably did not encounter this effect. All this serves to indicate the advisability of compatibility tests between samples of a plastic and a proposed recipe before expensive machinist's time is used to make an actual cell.

—CHARLES ERWIN COHN
Institute for Nuclear Studies
The University of Chicago
Chicago, Illinois

Higher-Activity Thulium

DEAR SIR:

Our article on portable thulium x-ray units (NU, May '54, p. 35) indicated that 200-mg MTR-irradiated sources would produce about 2 r/hr at 1 ft. This figure was estimated from results with our oxide sources; it now turns out that these sources were not irradiated at maximum MTR flux. We have now received the first shipment of four 200-mg thulium metal sources that were irradiated for three months at approximately the maximum MTR flux.

Each of these sources yields 10 r/hr at 1 ft, or about five times the intensity mentioned in our article. Thus, exposures of about 4 sec are adequate for a radiograph at 1 ft using Parspeed Patterson intensifiers and Blue Brand film. At 8 in., an exposure of only 2 sec would be required. It is possible that faster film combinations might reduce these exposures to less than 1 sec at 8 in.

H. E. Seeman of Eastman Kodak Research Laboratories points out that the film sensitivity curve on Fig. 3 of the article represents principally the sensitivity of the intensifying screen, so that Ag and Br discontinuities should be much less pronounced, while a discontinuity should appear at the energy of the W line, due to the W in the screen. Fortunately, this error does not affect the practical application of this curve as a guide for comparative exposures.

The fact that the intensity of the newer sources is greater than we had supposed may permit use of these sources for additional purposes. On the other hand, sources of this strength require more shielding than indicated in our article. Thus, where portability and cost is important, 50-mg sources in light shields still may be preferred.

Over 30 units, each containing 200 mg of thulium metal, are now being irradiated in the MTR. Mr. John Flaherty, Manager, Chicago Operations Office, U. S. Atomic Energy Commission, can supply information to those interested in obtaining one of these sources for experimental work.

—SAMUEL UNTERMYER
*Argonne National Laboratory**
Lemont, Illinois

A Source of Sockets

DEAR SIR:

The article in the April issue of NUCLEONICS (p. 44) by J. C. Baker and G. G. Eichholz entitled "Reliable Scaling Circuits for Decade Tubes" was timely and of considerable interest to me. We have done some work with these tubes and hope to do much more.

I would like to point out an item that may be of interest to the readers of this particular paper. The authors state that they could not obtain the duodecal sockets for use with the Philips EIT and the Nomotron tubes. There is such a socket available. It is called the Philips Duodecal Socket Type 5912/20 and is available from the Amperex Corporation, Hicksville, New York.

I am not sure of the price of this socket. We ordered our tubes from Amperex Corporation and included an order for sockets at an estimated price of 50 cents each. They arrived at our estimated price, which seems to me to be low in comparison with other similar sockets. A recent DuMont photomultiplier tube also used this same socket.

—DONALD MORKEN
Radioactive Inhalation Section
Pharmacology Department
Atomic Energy Project
The University of Rochester
Rochester, New York

Research Reactors: Cost and Performance

DEAR SIR:

The cover of the April, 1954, issue of NUCLEONICS and the article by J. A. Lane (p. 12) from which the cover is derived, could be very disturbing to some people, especially to those who have an acquaintance with the field of research reactors. Although Mr. Lane's analysis is worthwhile as far as it goes, it is far from complete, and people who are not familiar with the rest of the story could draw some very erroneous conclusions. An evaluation, such as is attempted here, is colored a good deal by where the emphasis is placed—whether it is on the word *research* or on the word *reactor*. The important thing in a research reactor is to *use* the neutrons, not just to cook them up. Using the neutrons is a function of a lot of other things besides the fuel and the moderator.

Mr. Lane's thesis is that research reactors of the future should use enriched fuel. One can hardly argue against this in view of the fact that the stuff is finally being made available. Why the CP-1, CP-2, X-10, and BNL reactors find themselves a part of this argument is a little hard to understand. The criterion for performance index is a little strange, since BNL and other graphite reactors manage somehow to carry on extensive research programs. This performance index could more effectively be peddled to power

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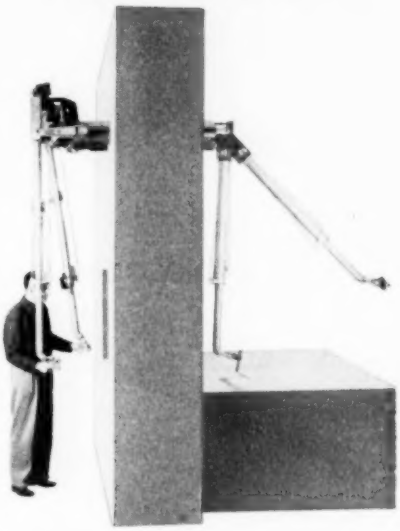

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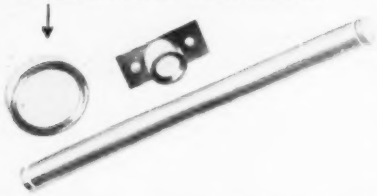

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Standards.....Alpha, Beta, Gamma

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industry people whose primary interest is usable heat. Experimental data do not lend themselves to this kind of appraisal.

The most flagrant disregard for presenting the full story is demonstrated by Mr. Lane's comparison between the fuel costs for the BNL reactor and an enriched reactor. This protest will not permit quibbling about the numbers Mr. Lane takes to be representative. But it does ask why no comparison is made between the lengths of time the two fuel loadings will last before they have to be renewed. The natural-uranium reactors produce plutonium, too; this is a large credit to be applied against the cost of the fuel. No mention, either, is made of reprocessing costs on the fuels, fabrication costs, or the operating costs attendant on each of the systems.

There are some costs, in this article, that should be argued. It would appear that the BNL reactor is the most costly of the research reactors built, to date. It cannot be denied that it is an expensive machine, but the cost assigned to it is misleading.

Others, of the costs presented, are also misleading. The breakdown on ORR, a "conceptual design of a reactor" is most vulnerable. Apparently, no site or any power are required for this reactor of the future. Also, apparently the building is going to be a quonset hut. No redistribution of costs is considered necessary in view of the fact that his breakdown applies to construction at ORNL, a going plant. Would the costs be the same if ORR was built in Iowa? Is it pertinent to ask how much has already been spent on the "conceptual design"?

The cost of $18-million assigned to the MTR, of course, does not include many years of development work, which comes for free to all reactors of the MTR type. Would the BSF have cost $250,000 if the MTR hadn't been designed? This is why it is so ridiculous to display such comparisons in a table titled, "Performance and Cost of Research Reactors," or to make a plot labeled, "Performance Index."

Although it has been conceded, at the outset, that Mr. Lane does make some points, it is nevertheless true that the design of a research reactor must be considered in terms of the research program it is intended to support. Anyone who picks a reactor out of these tables without anticipatory thinking about the manner in which the neutrons are going to be used would be remiss in his thinking. The reason the BNL reactor is so costly is because it is very large physically, with all kinds of costly gadgets built into it to support a large program of research, both here and elsewhere, in all fields of science. It might be mentioned, by the way, that the BNL reactor could also be loaded with enriched fuel, now that it is available, to raise its flux into the 10^{13} and up region, and raise it off the "lowest performance" line.

—Marvin Fox
Chairman, Reactor Department
Brookhaven National Laboratory
Upton, New York

AUTHORS REPLY. First of all, I should like to point out that the article is an abstracted version of a talk, directed toward a group of university people interested in building a reactor for academic research. The performance criterion of highest thermal neutron flux per dollar invested in research facilities was selected on this basis. In the talk itself, I emphasized the point that this was not the *only* index of performance and that other factors, such as the accessibility of the neutrons for experimentation and the number and type of experimental facilities, were equally important. Certainly, the choice of a research reactor type depends on the various kinds of experiments to be carried out, and high neutron flux is not always the most important factor.

In selecting a system, one must always weigh the relative merits of large-volume lower-flux cores versus small-volume higher-flux cores. The CP-5 falls into the former category and is considered by the Argonne National Laboratory staff to be preferable to the higher flux light-water machines. A better measure of reactor performance, which would take both experimental volume and neutron flux into consideration, might be the total number of usable neutrons produced per second per dollar invested; however, data were not available for such a comparison.

With regard to Mr. Fox's comments defending the usefulness of the BNL and other graphite reactors for research, I had no intention of implying anything to the contrary or deprecating the Brookhaven reactor. I am fully aware of the wonderful research job our own X-10 graphite reactor is doing and assume the same is true for the BNL reactor. At the same time,

I would scarcely recommend that a university duplicate the X-10 pile.

The comparison of fuel costs in the article was directed toward *fuel investment* costs rather than fuel replenishing costs. Actually, fuel investment costs were not included in the comparison of the reactor types, and the point was only raised as one of supplementary interest. Costs due to fuel burnup are negligible in most reactors of interest to universities and, consequently, were not considered. In reactors with very high fluxes, such as the MTR, fuel costs due to burnup, reprocessing and fabrication are an important part of operating costs and probably greater than the corresponding costs for natural-uranium reactors, as Mr. Fox correctly points out.

With respect to the comments regarding the costs of the ORR, I question the use of the word "vulnerable." We feel that these are sound values for construction at any location (ORNL was *not* specifically mentioned as the location of the proposed design, as Mr. Fox infers). The proposed $600,000 building was to be a very attractive and practical structure, rather than a quonset hut. Site costs were not included since they were unknown. Power requirements are small, and a separate power plant not required. With respect to ORR design costs, the given figure of $300,000 includes conceptual design. Development costs were neglected *for all reactors* considered since data are unobtainable. These costs are not pertinent for a consideration of university reactors since the technology is now available for all types that were compared.

Finally, I am inclined to agree with Mr. Fox that a thorough consideration of the end use is a necessary prerequisite to the selection of a university reactor. It is my feeling also that a comparison of reactor designs on the basis of over-all costs leaves something to be desired and that one should interpret the results in a qualitative rather than a quantitative manner.

However, the conclusion that highly enriched water-moderated systems can provide more neutrons per dollar invested than other types of nuclear reactors is valid regardless of possible inaccuracies in individual costs used as a basis for comparison.

—J. A. Lane
Director, Reactor Experimental Engineering Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee

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NEWS

AEC Opens MTR Facilities to Broader Research Use

Specialized facilities of the Materials Testing Reactor (NU, April '54, p. 20) at the National Reactor Testing Station, Idaho, have been made available by AEC for use by non-AEC contractors.

Even portions of the reactor's greatest neutron intensity (also the world's highest), which must be used primarily for AEC projects, will be available part of the time. Because of security considerations, experiments will be performed by the Phillips Petroleum Co., which is operating the reactor for the Commission.

Charges will be based on all costs involved, including depreciation, overhead and operating expenses; but they are considered sufficiently low to bring the service within the means of qualified research organizations.

Applications should be filed with the U. S. Atomic Energy Commission, Isotopes Division, Oak Ridge, Tenn. Phillips Petroleum Co., Idaho Falls, Idaho, should be contacted directly for information concerning technical questions relating to irradiation services, scheduling, price lists, and arrangements for obtaining these services.

Plan '55 Engineering Meeting at Berkeley

Plans are being made to hold a conference on nuclear engineering at UCLA on April 27–29, 1955.

The program will be designed to have maximum value for engineering personnel working in the field. Accordingly, its scope will be more limited than that of previous conferences.

Two major topics have been selected. Under the first, emphasis will be placed on design, construction, operation, behavior, and economics of complete reactor systems. Nuclear powerplant papers will cover power-extraction systems and auxiliaries for liquid-metal systems, light- and heavy-water systems, and gaseous (air and helium) systems. System dynamics will be covered by papers on dynamic behavior and stability criteria as well as instrumentation, control, and calibration.

Under the second major topic, attention will be given to industrial utilization of radiation from reactors, fission products, accelerators, and isotopic sources. Engineering analysis, design, development, and economic factors will be considered.

Information can be obtained from R. A. Fayram of the University of California's mechanical engineering division at Berkeley.

AEC Continues Instrument Development Activities

Fiscal year '55 will see AEC expenditure of $500,000 for improvements in scintillation counters, dosimeters, and telemetering equipment.

Research is in progress at Notre Dame University, RCA, and Allen B. DuMont Laboratories. Major effort is being directed toward basic and applied research on photoelectric effects, improvement of photomultiplier transit spread characteristics, and on development of large photo-cathode multiplier tubes of 30–36-in. diameters. Model shop fabrication is proceeding on test quantities of tubes developed under the program. Major portions of the work are being done by commercial manufacturers, but university groups will supplement the basic studies.

A standard laboratory instrument is being developed to measure the kilo- and megaroentgen doses encountered with large radiation sources currently in wide use.

A simple, easy-to-use instrument is being developed to measure the relative proportion of neutron and gamma dose as well as the total. Need for such an instrument was demonstrated in recent weapons tests.

Telemetering equipment now being developed for weapons tests also will be useful for measuring radiation levels and meteorological data at locations surrounding reactor power stations.

Five Northwest Utilities to Study Nuclear Power

AEC has agreed to permit five utility companies of the power-short Pacific Northwest to study the feasibility of designing and constructing a power reactor. This makes the 13th reactor study being made under the Commission's industrial participation program.

The five companies making up the new team are: Montana Power Co., Butte; Washington Water Power Co., Spokane; Pacific Power and Light Co., Portland; Portland General Electric Co., Portland; and Mountain States Power Co., Albany, Oregon.

The companies will finance the team's one-year study of AEC's power-reactor development program. After considering research and development problems and economic factors, the team will report their findings and recommendations to the Commission.

Bloch to Head CERN; Laboratory Being Built

Felix Bloch, Stanford professor and Nobel prize winner in '52 (NU, Dec. '52, p. 84), has been named director of the European Nuclear Research Council. At an April meeting, the Council also decided to start foundation work in May on its 45-acre research center near Geneva.

Managing board of the new council consists of Bloch, Eduardo Amaldi, and C. J. Bakker. Bloch will move to Geneva in September. Amaldi, a professor at Rome University, was named assistant director of the Council. Bakker, a professor at Amsterdam University, was made representative of the chiefs of the Council's various scientific groups (NU, Jan. '54, p. 73). Britain's Sir Ben Lockspeiser has headed a special working group to study administrative and financial matters.

Costs. The Council plans to spend $30-million during the lab's 7-year construction period. A 20–30-Bev proton synchrotron is expected to cost about $14-million and take 7 years to complete; a 600-Mev synchrocyclotron, about $4-million and 4 years; the laboratory, about $5.4-million for buildings and scientific equipment ($2.4-million of this is for general electrical, heating, and access installations), taking 4 years. Theoretical studies and other forms of cooperative effort will cost about $1.5-million. Administrative and operating expenses will involve $4.4-million.

Yearly operating costs of the completed laboratory will be about $2.3-million on the basis of a paid staff consisting of 75 graduate research workers, 130 technicians, and 100 clerical and manual workers. The 12 sponsoring nations will absorb this cost on a percentage basis (NU, Sept. '53, p. 77). Research fellows may be supported by special grants from member countries or UNESCO. Facilities also will be offered to a limited number of senior researchers who will be paid by their national institutes.

About 50 people of eight different nationalities are working at Geneva on preliminary plans and tests for the laboratory and equipment.

Other groups are using existing equipment in various universities of Western Europe. Work is being done at the Universities of Paris and Heidelberg, at the Christian Michelson Institute in Bergen, the Physics Institutes of Geneva and Upsala, and at Harwell. Much of this work is being done without charge to the Council.

The various groups will move to Geneva gradually, but it will not be before 1961, at best, that the laboratory will be in full operation.

Proton synchrotron. The strong-focusing principle will be utilized (NU, Nov. '52, p. 106). A group working in Paris under the direction of O. Dahl has been striving to resolve technical problems concerned with the proton synchrotron. Their investigations have dealt with effects of: azimuthal irregularities resulting from use of a linear variation of the field with the beam, use of a non-linear field, practical alignment of the machine, possibilities of working with transition energy, modification of the alternative disposition of positive and negative sectors, and usefulness of scale models.

The degree of precision needed for magnetic measurements is being established by means of a d-c electromagnet model. A larger a-c model (6 metric tons) is under construction.

Experimental work and tests on electromagnet models will probably continue for two more years before high-frequency control problems are solved. No scale model of the complete machine is planned. J. P. and M. H. Blewett, on leave from Brookhaven, recently joined the group. A subgroup at Heidelberg also is studying high-frequency problems.

The 30-Bev machine, with a 140

Washington Report

Not since the famous Hickenlooper "incredible mismanagement" investigation of the first AEC chairman, David Lilienthal, in 1949 has there been any public airing of disagreements among the members of the Atomic Energy Commission. In hearings last month before the Joint Committee on Atomic Energy, a serious split over the role of the AEC chairman came to light.

The second version of the Cole-Hickenlooper bill to amend the McMahon Act proposed that the chairman "shall be the principal officer of the Commission." Some proponents of this wording maintained that there was no intention to increase the power of the chairman. Other proponents felt that, in any event, the powers of the chairman should be increased. The opposition maintained that the fact and spirit of an equal-power five-man group should be kept.

At the conclusion of the public hearings, the Joint Committee, in executive session, unanimously agreed that each of the five commissioners should have equal responsibility and authority and that the law should spell out the duties of the AEC chairman but he should have no increase in powers.

Although the issue is now apparently a dead one, it is of interest in that it sheds light on prevalent attitudes and the feeling of several commissioners that an inharmonious atmosphere exists within AEC.

Specifically, these are the main points of view:

• **Rep. Cole** (chairman, Joint Committee)—"We are not trying to change the position, the authority or responsibility of the chairman of the Commission in any respect . . . Each member of the Commission shall continue to have equal authority." A sidelight point that Cole expressed in tentative fashion is that he does not feel that each commissioner should, by law, have full access to all information necessary to carrying out this authority because he feels that at some time some commissioner might become a security risk.

• **Rep. Holifield**—He expressed his views by quoting the majority report filed after the Hickenlooper investigation. "The framers of the McMahon Act deliberately established a five-man directorate rather than a single administrator to control our atomic enterprise for the very purpose of assuring that diverse viewpoints would be brought to bear on [far-reaching] issues. The possibility of split votes was not only anticipated but regarded as wholesome." In further supporting the present form of AEC set-up, Holifield cited Admiral Strauss' dissenting vote in favor of a crash H-bomb program in 1949 that led to the start of such an effort.

• **Commissioner Strauss**—He essentially agrees with the principle of a five-man commission but states that it is "not possible, effectively, to *operate* a large business enterprise by committee . . . Decisions are numerous and demanding—in many cases urgent. Many cannot be handled by referendum." In another statement, he implied that the general manager should report only to the chairman rather than to all five commissioners. Strauss further feels that it is "important to the good functioning of this great agency" that the law should delineate the responsibilities and duties of the chairman.

• **Commissioners Smyth and Murray**—They felt very strongly that Strauss was not keeping them fully informed on matters on which they should be advised and that the proposed revision in the law might aggravate this situation. Smyth felt that if the change went through, full-time commissioners would not be necessary.

• **Commissioner Zuckert**—"No step should be taken which is even subject to doubt as to its effect [on the concept of five-man rule] . . . . The fact that we are dealing with things that must necessarily be secret makes it undesirable to put too much power in the hands of one man . . . There is still a pioneering task [ahead] . . . Policy and operations are far more indistinctly separate in our work than they are in an established operation."

• **Commissioner Campbell**—He is strongly inclined in favor of one-man rule of AEC.

meter orbit radius, will be relatively isolated from the rest of the laboratory. The magnet sections will be buried in a deep circular trench covered with earth. A laboratory building will contain the magnet power supply, target and equipment area, and a 10–15-Mev linear accelerator will be used for injection. The high-frequency power supply will be in the center of the circle.

Synchrocyclotron. Under the leadership of C. J. Bakker, the group working on plans for the synchrotron has nearly completed its work; construction contracts are expected to be signed soon.

The electromagnet's polar parts will be 5 meters in diameter. Tests have been run on a $\frac{1}{48}$-scale model of the polar dises. A $\frac{1}{10}$-scale model of the magnet is being made for shimming measurements. In cooperation with the Philips Works at Eindhoven, a $\frac{1}{4}$-scale model is being built of the FM system's vibrating rod.

General. The fundamental nuclear research will be confined strictly to nonmilitary studies. Theoretical studies will be conducted under the direction of Niels Bohr. Cooperation with national research organizations will be encouraged.

Efforts will be made to achieve a balance between experienced permanent staff members and visiting or inexperienced personnel.

AEC Authorizes Two New Heavy-Particle Machines

AEC will spend $1,200,000 toward construction of each of two heavy-particle linear accelerators. They will be built within three years at Yale University and the University of California's Radiation Laboratory at Berkeley.

Nuclei ranging from beryllium to neon will be accelerated to 10 Mev/nucleon. Thus, neon (with an atomic weight of 20) will be accelerated to 200 Mev. It might be possible to accelerate atoms as heavy as silicon.

Yale's project will study physics of heavy-particle nuclear interactions. The Berkeley machine will be used primarily for nuclear chemistry studies and new-isotope production.

The accelerators will be 7 ft in diameter and 108 ft long. Injection of particles into the accelerating barrel will be achieved by a Cockcroft-Walton machine.

PERSONAL COMMENTARY:

Atomic Energy Research in England and France

By D. J. HUGHES
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Since September of 1953 I have had the good fortune to spend my time in an unhurried manner, as a Fulbright professor, about equally divided between the universities of Oxford and Cambridge, along with short visits to other research centers. Outstanding among the latter was a week spent at the French atomic laboratory at Saclay. Although my primary function has been to lecture on neutrons and nuclear structure, ample opportunities have been available for reasonably thorough studies of the unclassified neutron research programs at Harwell and Saclay. Before returning home, I hope to make similar visits to several other atomic sites in Europe, places where rapid progress is being made in applied neutron research.

My impression is that . . .

In the present account I intend to relate some of the impressions I have gathered, not only during visits to the atomic laboratories, but also in conversations with those scientists who, while not actually stationed at the research centers, are vitally interested in the proper conduct of national atomic energy research. As the broad aspects of fundamental reactor research* were my principal interests during the visits, and because engineering aspects of the large-scale plans are given in technical reports, I shall incline toward somewhat intangible matters—the broad emphasis of the programs, the general outlook of the scientists both as to their own work and that in the United States, their hopes and their worries. The impressions described here and the conclusions reached come not from official reports but rather from many personal contacts spread over the last 6 months.

Britain is . . .

In trying to select a single outstanding general impression characteristic of all the European effort, I invariably return to an opinion first expressed to me by F. E. Simon, of Oxford, an opinion later reinforced many times by others. Greatly impressed by the magnitude of a complete atomic energy program, he felt that it could very well prove to be more than any single European country could manage. He talked of the production of uranium metal and of heavy water, chemical separation of plutonium, enrichment of uranium by gaseous diffusion, bomb development, and the basic research on which all of these depend. The prospect of building an atomic energy industry while still recovering from war's depletion of nonatomic industries is truly an overwhelming task.

developing all phases . . .

My immediate reaction to the view expressed by Simon and later by others was, "Why try to do it all yourself? Why not cooperate with other European countries or depend on the United States for solution of some of the problems?" But as time went on, and conversations continued, I gradually began to see the reasons more clearly for the British view and to realize that by and large it was correct for them, in their long term view, to develop *all* phases of atomic energy, from tracers to bombs. It wasn't merely the present lack of exchange of information on industrial applications of atomic energy that led to a feeling of "we'll go it alone," but in addition, and of greater weight actually, a feeling that the only way to develop a sound and substantial atomic energy industry was for the British to become experts in *all* its phases. It is difficult to decide, of course, to what extent national pride contributes to this conclusion, but all things considered, and correcting somewhat for this last effect, it certainly is the logical basis for the British effort. And the British program is well designed to cover all phases of the atomic energy field, yet in a planned, orderly way so that, while practical results will be felt as soon as possible, the over-all mastery of the field will proceed simultaneously albeit slowly.

in an orderly fashion.

An immediate impression gained in

*I here use the phrase "reactor research" in deference to usage in the United States, but with a twinge of regret, for I prefer "pile" to "reactor" and I did note with interest that the former term is used almost universally in Europe.

discussions of this program is that it is orderly, well-integrated, and will give practical results quickly, not only in military applications but in production of electric power. An over-all order exists that is striking when compared with the many reactor projects in the United States, the varying fortunes of different reactors, the Congressional discussion of technical matters with all the attendant publicity, the hue and cry for "industrial participation," and the ever-present concern for security of secrets. This difference is real, in my opinion, but there are certainly reasons for it other than the British talent for orderly management and the present civil service status of most of the workers. The well-integrated nature of the entire program relative to that of the United States seems to arise partly from its smaller size, and to a greater extent, from its clear-cut goal arising from the power-hunger of Britain. The need to replace the dwindling coal supply with some other power source will become so acute that it can almost be said that Britain cannot get along without atomic power production by the turn of the century. Importation of coal has now begun, in spite of great efforts to increase domestic production, and prospects are that it will increase (coal is being carried, not to Newcastle, but at least to England).

But generation of . . .

The present form of the program illustrates well the emphasis on power. Two Hanford-type (although air-cooled) plutonium production piles are in operation at Windscale, building up a stock of fissionable material for bombs or for power-breeders. The first power-producing pile is now being constructed at Windscale, also; nothing radical in design, but something that will work *soon*, and reasonably well. Instead of atomic-powered submarines, aircraft-carriers or airplanes, we have here a simple graphite-moderated, natural uranium pile. Its only radical "new" feature is compressed-gas (CO_2) cooling, although this method (with nitrogen as coolant) has been in use at the French "P2" pile at Saclay for a year. Such a simple pile would hardly be considered as a "power reactor" in the United States, yet this old-fashioned pile will be operating in a year or so, producing about 40,000 kw of electricity, thus replacing in full

Sidelights

PWR auxiliary design work subcontracted. Stone & Webster Engineering Corp., a Boston firm, will perform architect-engineering services on the pressurized-water reactor as subcontractor under Westinghouse Electric Corp. The firm will design reactor foundations, the reactor building, fuel-handling facilities and other auxiliaries.

●

Two universities award reactor-controls contracts. Two universities, Pennsylvania State and Michigan, have awarded contracts to Leeds & Northrup Co., Philadelphia, to provide complete control instrumentation for their research reactors. Equipment includes electronic recorders (to show power level and its rate of change) together with cables, controls, and drive mechanisms for positioning control rods.

●

Multicurie fission-products plant for ORNL. $1.5-million will be spent on building and equipping a plant to chemically separate, purify, and fabricate kilocurie fission-product sources. It will be capable of preparing one-hundred 2-kilocurie Cl^{137} sources per year and will provide for separation of Sr^{90}, Ce^{144}, Ru^{106}, and Pm^{147}, and other sources. Savannah-River plant wastes will be the raw material.

●

New waste treatment facility. A $180,000 waste treatment plant at ORNL will decontaminate 750,000 gallons of low-activity, high-volume waste daily. The unit will cut the daily curie discharge by more than 50%. With this equipment, research efforts eventually will result in modifications that will cut discharge by 90% or more.

●

West Germany plans research center. The first postwar nuclear research center in Western Germany will be built near Munich, according to present plans. Werner Heisenberg will probably direct construction of a research reactor.

●

Uranium bonuses total $3-million. AEC has paid more than $3-million in bonuses to uranium miners since March, 1951, when bonus payments to stimulate production went into effect. Payments are running about $175,000 per month. Payments double the base price for the first 10,000 lb of uranium oxide produced from any new find. The bonus ranges from $15,000 to $35,000, depending on grade. The bonus program will extend through Feb. 28, 1957.

●

Japan studying radiation sterilization of food. Japan's welfare ministry has granted a small subsidy for research on radiation sterilization of food.

●

Smyth makes power estimates. AEC Commissioner H. D. Smyth recently calculated that 140 reactors of 150-Mw capacity will be operating in the U. S. by 1975 if nuclear power cost is 7 mills in 1963 and is reduced to 4 mills by '75 (assuming half the new plants built will be nuclear if power costs are equal). There will be 33 such reactors in 1957 if 7-mill nuclear power is not attained until 1965 and costs are cut only to 5 mills by '75 (assuming that nuclear plants will be built only if they have an advantage of 1 mill/kwh over conventional plants and even then only 50% of the new plants in that cost range will be nuclear).

●

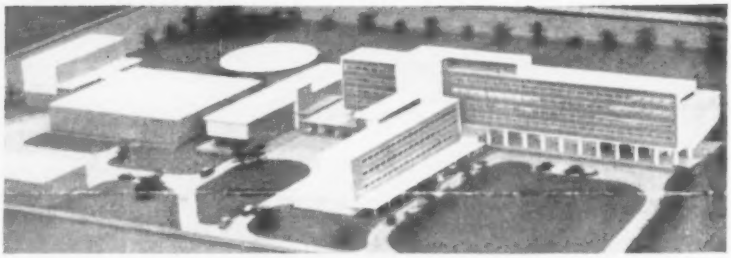
Tritium studies in Israel aided. A $28,000 Ford Foundation grant has been made to the Weizmann Institute to assist in studies of tritium-concentration measurements to determine ages of underground water supplies.

●

Arco chemical processing plant being modified. The National Reactor Testing Station's chemical processing plant for reclaiming U^{235} from used fuel elements is being modified.

operation the consumption of about 200,000 tons of coal per year.

At the same time the more remote phases of the program are proceeding. In February of this year it was announced that "Zephyr" a zero-energy fast neutron breeder had been operated for the first time, using plutonium from Windscale as fuel. The depleted uranium resulting from the Windscale operations is not forgotten in the national picture, but goes to Capenhurst for enrichment by gaseous diffusion and is then converted to fuel for the Windscale piles again. In addition, design studies have begun on a pressurized light-water power reactor. The emphasis on power as soon as possible, on an economic basis, and a longer-term view toward the most efficient integrated schemes, is abundantly evident in these interlocking activities.



NEW HOME OF INDIA'S TATA INSTITUTE of Fundamental Research is shown in this model. When the $1¼-million center is completed late next year it will include accelerator facilities, laboratories, and administrative offices for physics and mathematics groups as well as for India's AEC

power is urgent goal.

This primary position of power production at stationary plants as a goal in the British program is obvious and it helps to give the entire activity a definite cohesion. There is no combination of goals, as in the United States, where mobile power, in the form of propulsive units, competes in the budget with stationary power producers, and at least until now, comes off rather better. The abundance of natural power sources in the United States also removes the sense of urgency with the result that there is an understandable reluctance to build any power reactor until lengthy projects have proved it to be the best possible.

The British view of their fuel situation, and its relationship to atomic power production is well illustrated by the discussions in Parliament arising in connection with atomic energy legislation. For example, when Lord Falmouth criticized the government program in the House of Lords on December 14 by stating that the plan to build a 50,000-kw power station at a cost of six million pounds should be replaced by a "less grandiose scheme," Lord Salisbury, who as Lord President of the Council is responsible for the new atomic energy corporation, answered with a detailed account of the reasoning behind the program. He explained that production of electric power, a vital matter to Britain and of great importance in the atomic program, should not be under control of the Minister of Supply, and hence had been placed in the new statutory corporation, of the type that now controls production of coal, electricity, and gas. The purely military aspects of atomic energy, i.e. bomb design and production, he explained, will not be a direct concern of the corporation but will remain an activity of the Ministry of Supply.

The optimism of Lord Salisbury concerning the future of atomic power in Britain is illustrated by his prediction that "with the program under examination realized, most of the country's electricity would be generated from atomic power by the year 2000." Lord Cherwell, who as Churchill's adviser was until recently responsible for the program, and Prof. Simon, men who understood full well the problems that must be solved before this happy state of affairs is realized, do not share this extreme optimism. Both, however, agree that atomic production of electricity is essential for Britain and that the strongest possible effort, which necessarily implies careful concentration of limited resources, is justified.

France also needs power . . .

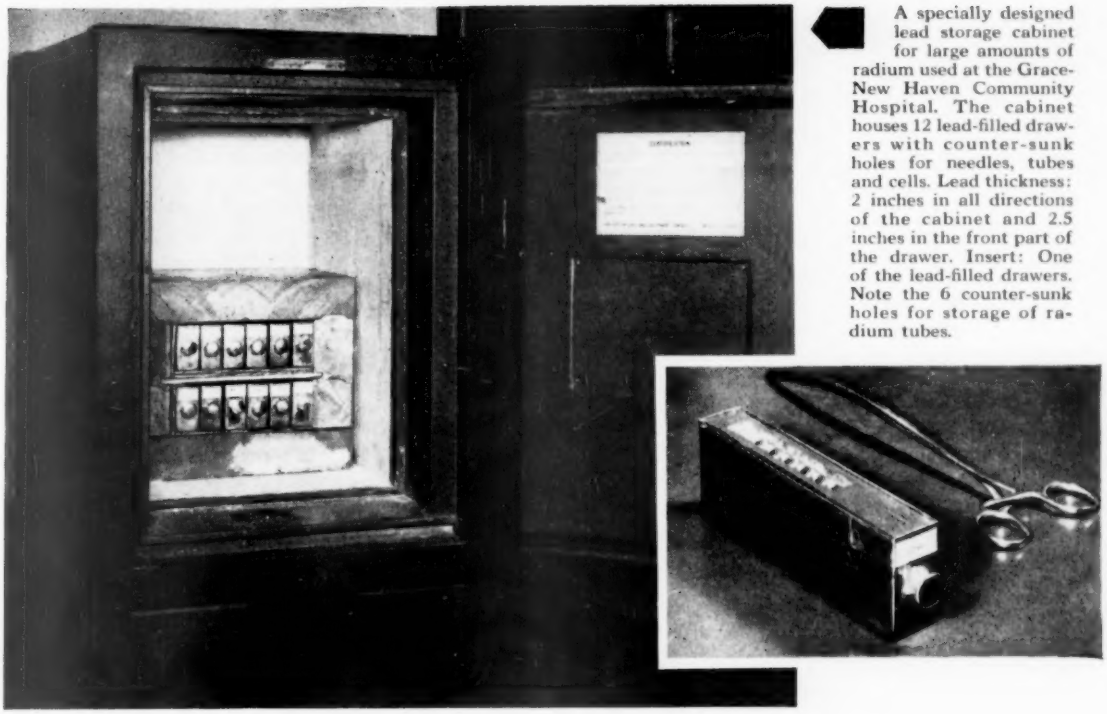
As Americans are more or less familiar with the well-publicized fuel shortage in Britain, the emphasis on power production in the atomic program is easily accepted. However, before arriving in Europe I hadn't heard nearly as much about the French fuel situation, hence was somewhat surprised to learn from the scientists at Saclay that, in their opinion, atomically-produced electricity was even more urgent for them than for the British. They told me that the French power load (about 4×10^{10} kwh per year) is now supplied about equally from poor coal and water power, with little chance of increasing either substantially. Power from tides has actually been given serious consideration but would not result in large increases in available power, would be expensive and of uncertain long-term reliability.

Atomic research now centers around P2, the heavy-water-moderated pile at Saclay that possesses a 4×10^{12} central thermal flux at present, with prospects of twice this flux when improved fuel rods are installed soon. As already mentioned, this pile has been successfully cooled by compressed gas (nitrogen at first; but now CO_2), the system planned for the British power pile now under construction. A 40-Mw plutonium-production pile is to be built at Marcoule (state of Gard), and some thought is being given to a high-flux research pile at Saclay, although the definite planning stage has not yet been reached.

as do other nations.

The keen interest in, and emphasis on production of stationary electrical power was very impressive to me as an American scientist, accustomed to the competing demands for effort and money in the atomic field, such as those of motive power of various types, that are important factors in our own program. It is well known that the emphasis of the other European countries, Norway, Sweden, Holland, Belgium, and others, is also on power production, and the plans of these countries, as covered in recent issues of NUCLEONICS, makes this fact evident without further discussion. The bare facts of these listings of plans, however, does not convey the spirit of determination that is gained by personal contact, the unity of each program that is dictated by the very real need resulting from power shortage.

There seems to be a fundamental difference between the attitude on the continent and in England concerning the "go-it-alone" approach already mentioned. The French scientists, for



A specially designed lead storage cabinet for large amounts of radium used at the Grace-New Haven Community Hospital. The cabinet houses 12 lead-filled drawers with counter-sunk holes for needles, tubes and cells. Lead thickness: 2 inches in all directions of the cabinet and 2.5 inches in the front part of the drawer. Insert: One of the lead-filled drawers. Note the 6 counter-sunk holes for storage of radium tubes.

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example, do not seem too concerned with the great problem faced by the British of carrying out all phases of atomic development themselves. Rather, they seem willing to use whatever help they can get from other European countries, the British, or the United States, and are willing to contribute whatever they can in return. This attitude, which is the only reasonable one in the light of the limited facilities of the individual countries on the continent, has already produced beneficial results. Examples of this cooperation are furnished by the joint nature of the pile at Kjeller, Norway (Norwegian heavy water and Dutch uranium), the fabrication of uranium metal by the French for the Swedish pile, the supply of uranium oxide to the French by Sweden, and the extensive interchange of scientists among the various research centers.

Basic pile physics is enhancing . . .

One striking characteristic of the neutron physics research itself at Harwell and Saclay—my principal interest—was the concentration on what could be called basic pile physics, such things as the constants of neutron diffusion in various materials, spatial distributions in complicated geometries, and neutron velocity distributions and temperatures in various lattices and moderators. In spite of all the measurements made in the decade of high neutron flux, these matters, all basic to the field of nucleonics, are still not well understood. On many occasions British or French scientists described the uncertainty in the neutron constants of the mentioned phenomena, and their plans to improve their own knowledge by experiments. Often they were rather unenthusiastic about the projected measurements for they were sure that very complete investigations had been carried out in the United States, but with results still buried away in secret reports. I was always able to encourage them unhesitatingly by explaining that their measurements would not be duplications, as these careful measurements unfortunately had not been performed and, had they been, their results would certainly be in the unclassified category.

The reasons, I would explain, for the sad state of some of these fundamental pile neutron constants may be found in the history of the war-accelerated progress of pile physics in the United States. When many of these constants were first measured, in the period 1940–1944, time simply didn't allow lengthy, detailed investigations. A practical, applicable result was wanted and, when obtained, measurements proceeded to the next desired constant. Later, when more time and more neutrons were available, many pile physicists (almost converted to engineers by then) had become interested in high or intermediate energy, enriched reactors, rather than simple, well-behaved, unenriched thermal piles. Although some physicists were concentrating on certain constants needed for reactors, e.g. accurate cross sections, this effort was also powerfully sparked by the interest in basic theories of nuclear structure. As a result of this history the old, hastily-measured numbers are often accepted as correct, and there are very few people at work in the United States on problems of neutron physics of a "basic applied" nature, that is, applicable to piles in general.

knowledge of fundamentals, and . . .

In Europe, on the other hand, there is activity both theoretical and experimental along these lines; the workers are trying hard to measure and understand, for example, any difference between the neutron temperature and the physical temperature of a pile lattice, to decide if the capture cross section of graphite can be measured absolutely and if so, to do it, to learn if the neutron distribution in a uranium slug corresponds to simple diffusion theory. They are not getting their answers by referring back to old reports based on hasty, incomplete measurements (I know, having made some of them myself). Actually, it would be of definite value to the United States atomic program to increase the effort in serious "basic reactor physics." The emphasis should not be on features of neutron behavior peculiar to individual reactors but on the basic things—diffusion, moderation, resonance absorption, velocity distributions—that are fundamental, more or less, to *all* reactors.

new research reactors will help.

The intense interest of the Europeans in the basic neutron physics of reactors is revealed in another way also—in the plans for research piles of high flux, that is, piles intended exclusively for research, not combined with power or plutonium production. Thus Harwell is pushing rapidly ahead on plans for such a research pile, to be built at Harwell, with a planned completion in two years. This pile will be heavy-water moderated, and will possess a central thermal flux of about 1×10^{14}, much higher than is available in any pile exclusively devoted to research in the United States. While it is true that the MTR has a 4×10^{14} maximum thermal flux, this reactor is not primarily devoted to research nor is it located at a research center—as its name implies its purpose is to test materials under high flux bombardment. The highest research flux in the United States at present is found in the Brookhaven pile, but its 5×10^{12} is hardly "high-flux" relative to present-day plans.

With regard to the future, the only research reactor under construction in the United States at the present time of higher flux than Brookhaven is CP5 at the Argonne laboratory, which will reach 3×10^{13}, somewhat less than the magnitude already available for several years at Chalk River and well below the proposed Harwell research pile. If it is generally agreed—and I am certainly convinced of this—that the atomic energy field has a strong dependence on high-quality neutron research for its progress, then the superiority of the European research piles to ours in the next few years certainly deserves serious contemplation (nothing is known to me concerning Russian possessions or plans relative to high-flux research piles). In addition to the increased effort in basic reactor physics already mentioned, sufficient flux should be provided, at *research* centers, for that effort. An increase in the emphasis, extremely weak at the moment, on basic reactor physics at the MTR pile would be of definite value, of course, in this connection.

But cooperation is hampered . . .

The cooperative nature of atomic energy development in Europe, which is obvious from even brief examination of the programs in the various centers, is an inevitable result of the limited potentialities of the individual countries concerned. The inevitability of this result, however, does not ensure that the difficulties of cooperative effort are thereby avoided, some of them constituting unusual hazards, primarily those related to exchange of information. Discussions with European scientists on this question of pooling of effort usually proceed to a consideration of the availability of research results, conferences for discussion of plans, and general publication policy, then of course to security.

by lack of information exchange.

After a number of such conferences and a close examination of the research under way in relation to security, I began to feel that there is a curious lack of information exchange, at least in basic reactor physics, that is not a *direct* result of security restrictions, for it is evident in many phases of the work that are completely unclassified. Scientists at one laboratory may be hard at work on a problem in applied neutron physics, let us say the measurement of the neutron distribution in a particular geometry, without apparently realizing that workers in other laboratories might be doing, or already have done, the same thing. I certainly received a definite impression that the rapid sharing of information that occurs in "normal" research—the "private" communication, the "preprint," the avid desire to publish, etc.—is missing to a large extent in the field of basic neutron physics of reactors.

The lack of communication evident in atomic affairs, even in those not hampered by secrecy, arises probably from several different sources, of somewhat uncertain relative importance. It may well be that the aura of secrecy surrounding all atomic energy activity tends to lead the workers to consider, without careful examination, *all* their work as secret. Perhaps the frequent necessity of performing classified along with unclassified work forces a framework of secrecy on both types; in an extreme form we would conclude that a laboratory is no more open than its most secret part, an extreme that has fortunately been well avoided thus far. Perhaps there may be a bit of national pride contributing as well, arousing a desire to do it all in one's own country without foreign aid.

Integration of research depends on...

A final matter of interest that was much discussed, especially in England, relates to the problem of fitting basic atomic energy investigations into the entire research program of the country. The correct relationship is much more difficult to attain in England than in the United States, for there are far fewer laboratories to cover the gamut from completely open to top secret work. In this connection it is helpful to conceive of Harwell as fulfilling the functions of Brookhaven, Oak Ridge, Argonne, and a few other laboratories rolled into one—and to some extent tending to acquire the security status of its most secret part. In spite of this

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featuring windowless operation for greatest sensitivity or "Micromil"* window operation for the newest and best method of counting soft beta radiation. *Newest*—because the exclusive "Micromil" window is so thin that it reduces the count rate for carbon-14 by less than 20%. *Better*—because common windowless counter problems (charge effects, chamber contamination, moisture accumulation) are completely avoided. Model D47 may be used with the automatic sample changer or chromatographic strip scanner—is the most versatile gas flow counter ever produced!

. . detects all soft or hard ionizing radiations

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serious drawback, Harwell in general seems to resemble Brookhaven most closely of the laboratories just named, an accomplishment, I suspect, in no small part due to its able and respected director, Sir John Cockcroft.

interchange of information, but . . .

It is true, however, that there is not much temporary exchange of personnel between Harwell and the universities, of the type that has contributed so much to the success of Brookhaven. Partly a result of security restriction, partly because universities are unable, or reluctant, to release staff members for appreciable periods, the lack of exchange seems to have a definite effect on the level of work and morale at Harwell. As might be expected, this effect is smallest in the applied work, and increases as one examines the research further in the opposite direction, that of basic unclassified nuclear research. The solution of this problem of course involves many others in addition to security, for example the supply of trained scientists, university salaries, and ability of universities to hire enough men for exchange purposes, matters too intricate to pursue further in the present discussion.

security and cost are obstacles.

The problems associated with cooperative effort, not only at Harwell but with regard to all British research, are brought to the fore at present by discussions concerning large particle accelerators. The problem arises in the same way as in the United States —from a realization that the machines are growing too large to be handled by individual universities. A Brookhaven-type national laboratory is the usual solution that is suggested but then the question arises: Should this be part of Harwell? It is true that security would give rise to some complications in this case. However, in my opinion, based on experience at Brookhaven, the gain to the entire Harwell program would far outweigh the possible danger to security. At present the compromise that seems to be favored is to build the machine, a proton linear accelerator incidentally, in the shadow of the Harwell fence, thus gaining the advantage of proximity with the least inconvenience arising from security restrictions. It is planned to have the maximum cooperation between Harwell and universities, both in the construction and use of the machine. This balancing of several opposed factors is a good example of the type of solution necessary in the present state of physics as a potent political force as well as a user both of gigantic machines and high investigative intelligence.

The writer is deeply grateful for the hospitality extended to him at Harwell, Saclay, Clarendon, and Cavendish laboratories and for the stimulating discussions with many individuals at these and other laboratories.

AEC Asks $22.3-Million for Equipment for 1955

Congress voted last month to provide almost every penny AEC had asked for purchase of laboratory and process equipment. The House had trimmed $3.1-million from AEC's requests for physical research and $435,000 from its proposed biology and medicine program, but the Senate voted to restore this.

In all, approximately $22.3-million is to be available for purchase of such equipment. A partial list follows:

Brookhaven, $300,000; for reactor and accelerators: Amplifiers, oscilloscopes, electroscopes, electronic scalers, analyzing and detecting and focusing magnets, crystal spectrometers, neutron time-of-flight spectrometers.

Sylvania, etc., $257,300; for research on reactor fuel-element design: Unspecified equipment.

Hanford, $442,000; for plutonium process development: Spectrographs, recording refractometers, induction furnaces, pulse analyzers, counters, microscopes, drying ovens, fluorimeters, magnetic scalers.

Savannah River, $457,000; for process development: Mass spectrometers, assay units, centrifuges.

Rocky Flats, etc., $370,000; for weapons and process development: Temperature regulating and recording devices, constant-temperature oven, electronic recorder, high-volume air sampler, tensile tester, fraction collector, saw, tracer-equipment, X-ray unit, X-ray photometer, pulse-height analyzer.

Oak Ridge, etc., $1,995,000; for production, research, and process development: Line-tube racks, compressors, vacuum pumps, instruments, X-ray units, electronic recorders, platinum crucibles and traps, spectrophotometers, vibrating-reed electrometers, alpha monitors, wide-angle mass spectrometer, hypersonic generator and transducer, X-Y recorders, nuclear resonance detector and controller, alphatron gages, mass-flow meters, acoustic gas analyzer, potentiometers, *p*H meters, variable speed drives, centrifugal and proportional pumps, agitators, liquid-level controllers, pulse counters, rectifiers, manifold recorders, cathatometers.

Los Alamos, etc., $4,048,300; for weapons development: Fabrication devices, monitors, oscilloscopes, sigma-type 250–350 ton press, high-frequency die-heating unit, synchroprinter, flexowriters, computer components, bolometers for power vs. time measurements, large searchlights for air transmission measurements.

Sandia, $2,582,000; for weapons assembly and test development: Field electronic test equipment, oscilloscopes, voltmeters, generators, signal generators, power supplies, electronic meters, modification devices, calibration devices, strain and temperature indicators and recorders, dynamic and static testing gear, X-ray analyzers, analytical balances, polariscope, strobolume light source, telemetering devices.

San Francisco, $2,189,000; for chemical and metallurgical experiments: Laboratory apparatus, accelerator equipment, vacuum furnaces, manipulators, hot cells.

Chicago, $2,716,000; for research and development on aircraft propulsion: Pumps, motors, filters, valves, heaters deionizers, meters, recorders, autoclaves, transformers, switch gear, actuators, gear boxes, furnaces, forming tools, instruments, electronic and hydraulic controls, amplifiers, oscilloscopes, ion chambers, flux meters, air and dielectric heaters, recorders, temperature and flow recording instruments.

Pittsburgh, $205,000; for reactor research: Spectrograph, devices for colorimetric analysis and loop studies, core fabrication and monitoring devices, remote control and critical experiment apparatus.

Argonne, $1,723,000; for reactor, separation, waste disposal, and materials research: Pumps, manipulators, autoclave, hydrogen brazing furnace, radiation instruments, helium leak detectors, induction heating machines, accelerator modifications.

Schenectady, $444,000; for submarine reactor development: Remote manipulators, ionization chambers, d-c amplifiers, high-speed scaling circuits, log amplifiers, micrometer, sprangle

pump, remote television system, multiple temperature recorder, multichannel analyzer, high-temperature furnace.

Ames, $128,000; for molten-metal-reactor studies: Thermal loops, magnetic pumps, vacuum and diffusion pumps, powerstats, precision lenses, microscopes, electronic recorders.

Idaho Falls, $282,000; for chemical processing and MTR operation: Air monitors, portable meters, alpha survey meters, neutron counters, automatic caulometers, handling devices.

$5,663,500; for miscellaneous process equipment: Detection apparatus, recorders, detection chambers, sample-handling mechanisms, hot-feed remote pumps, ring balances, evaporator heat exchanger, bellows valves, pumps, compressors, ingot heating baths, micronizer and grinding equipment, arc melting apparatus, recording pyrometer, ore conveying and treating devices, casting equipment.

$600,000; for miscellaneous research: Equipment for various small contractors to the Divisions of Biology and Medicine, Raw Materials, and Research.

RAW MATERIALS

South Africa. Uranium profits of five gold mines showed a sharp jump during the March quarter ($3.85-million) compared with the last three months of 1953 ($2.5-million).

Randfontein Estates' large plant has started processing uranium-bearing slimes pumped from the nearby property of East Champ d'Or.

Bulgaria. The Soviet-controlled GORUBSO company is reported intensifying its uranium mining efforts in Bulgaria. Over 4,000 workers are mining the old uranium site at Buhova, where another new deposit has been discovered.

The Soviet company is also developing a second large mine located between Madan and Zlatograd in the Rhodope mountains. Up to 300 trucks daily are reported carrying ore to Podkova for shipment by rail to the Soviet Union.

Ethiopia. Uranium ore, described as a "major find," has been discovered. Details of the find's size have not been established.

NEWSMAKERS

George A. Boyd, formerly professor of biophysics at the University of Tennessee and senior scientist at the Oak

"PERSCINTICON" SIMPLIFIES AND ACCELERATES PROCEDURE IN DIAGNOSIS OF THYROID DISEASE WITH I-131

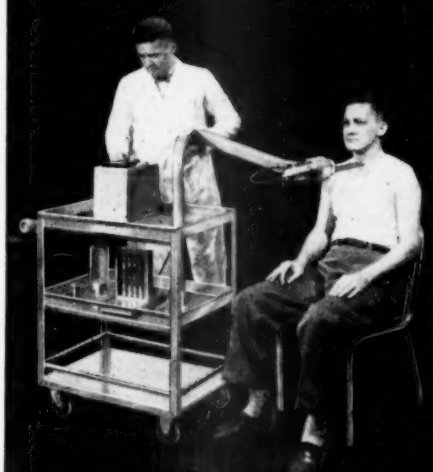
. . . Read thyroid uptake and urinary excretion of I-131 as a percentage of the control standard. No calculations are required.

. . . Elimination of calculations minimizes chance for error—saves time.

. . . Testing becomes a routine procedure—a greater number of patients are accommodated.

. . . Adequate accuracy. Efficient, compact equipment placement.

Rapid, accurate evaluation of thyroid uptake of I-131 is achieved with the Perscinticon. Minimum experience with isotopes is required.* Adapting the Lewis** method for determination of thyroid function with I-131, the percentage uptake and percentage of Urinary I-131, compared to a control standard, are read directly on the ratemeter, thus eliminating conversion calculations and permitting a more rapid handling of patients.



Thyroid uptake is determined with a sensitive, lead-shielded, collimated scintillation counter supported at the end of a positioning arm. A neck-thyroid phantom holds the I-131 control standard for initial adjustment of the meter to 100%.

An encased array of ten high-efficiency, G-M type 6306 tubes is used with the ratemeter to determine urinary I-131. Equal volumes of the diluted control standard and collected urine are successively positioned before the tube array. The ratemeter indicates the urinary I-131 as a percentage of the standard.

*Write us for a reprint of AEC requirements.
**J. W. Lewis, M. D., Colorado Springs Medical Center, Colorado

MODEL 596 RATEMETER

The ratemeter scale is graduated in percent. Four controls for zeroing out background, coarse and fine sensitivity adjustment, and time-constant selection permit rapid adjustment.

A sturdy hospital cart on 8" rubber tired, locking, swivel casters carries the ratemeter, the positioning support arm (extendable to 41"), the collimated scintillation counter with ¾" lead shielding around a 1" by 1" crystal, and the counter tube array. The shielded scintillation counter weighs only 10¾ pounds. Either counter is connected interchangeably to the single ratemeter.

MEDICAL INSTRUMENTS DIVISION
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Ridge Institute of Nuclear Studies, has been named director of the Arizona Research Laboratories. An autoradiography service laboratory is the group's first entry in the nucleonics field.

R. A. Charpie has been appointed assistant research director of Oak Ridge National Laboratory. His duties involve the mathematics panel, educational, health physics, and metallurgy divisions. **E. H. Taylor,** formerly assistant director for chemical sciences, is now director of the chemistry division; **S. C. Lind,** formerly acting director, becomes senior adviser to the chemistry division. **G. E. Boyd,** who has been associate director of the division, has been appointed assistant research director for chemical sciences. His duties involve the chemistry, analytical chemistry, materials chemistry, and solid state divisions. **C. W. Sheppard** has been appointed to a newly-established assistant directorship in the biology division.

John E. Gray has resigned as director of the technical and manufacturing division of AEC's Savannah River operations office. He will join the atomic power division of Duquesne Light Co., Pittsburgh. **Winston Davis** succeeds Gray as director.

Four more members have been elected to the board of directors of the Atomic Industrial Forum. The new members are: **Gordon Dean,** now with Lehman Bros. (formerly AEC chairman); **Frank Pace, Jr.,** executive vice president, General Dynamics Corp. (formerly Secretary of the Army); **Arthur H. Bunker,** president, Climax-Molybdenum Co.; **Leonard W. Cronkhite,** president, Atomic Instrument Co.; and **J. Carlton Ward, Jr.,** president, Vitro Corp. of America. There are now 19 directors.

MEETINGS

September 13-15: Analytical Instrument Clinic; Philadelphia, Pa. Theory, applications, and design features of various advanced analytical instruments will be covered in a series of three-hour sessions. The clinic is sponsored by the Instrument Society of America in conjunction with the First International Instrument Congress and Exposition. Registration forms (required) and information can be obtained from Axel H. Peterson, Mellon Institute, 4400 Fifth Ave., Pittsburgh 13, Pa.

October 6, 7: Institute of Radio Engineers' Conference on Nuclear Science (NU, May '54, p. 79).

Patents

Government-Owned Inventions Available for License

THE FOLLOWING PATENTS were issued on inventions assigned to the U. S. Government. These inventions are available for license, ordinarily on a nonexclusive, royalty-free basis, on application to the administering agency indicated.

Printed copies of the letters patent may be obtained from the Commissioner of Patents, Washington 25, D. C., at 25 cents a copy, payable by check or money order. Specify the patent number and title when ordering.

These abstracts have been furnished by the Index of Inventions, maintained by the Government Patents Board, Washington, D. C.

Distillation system for recovering spent pumping oils* (2,668,794), Robert J. Schmidt—Vacuum diffusion pump system comprises section for distributing oil vapors, reduced pressure section, fractionating section, condensing section, and reflux section. Reduced-pressure section is provided with vacuum gage and outlet valve for withdrawing accumulated process oil.

Electromagnetic fluid pump* (2,669,183), Nat H. Godbold—Conductive fluid is passed through channel between stator of induction motor and locked rotor. Current is induced in fluid by rotating magnetic field. This causes rotation in fluid that is converted by centrifugal force into linear momentum.

Means for improving the yield from betatron X-ray generators† (2,669,652), Gail D. Adams, Donald W. Kerst—In accelerator, electromagnet comprises evacuated channel between poles, thin support of insulating material between poles, and field-correcting coil on the support. Continuously energized coil cancels residual flux from magnet when flux from remainder of magnet is at a minimum in energization cycle.

Electromagnetic fluid pump* (2,669,931), Nat H. Godbold—Channel filled with electrically conducting fluid passes up through magnetic core and into concentric passage. Electric current is passed through fluid in same direction as its flow. Induced rotary momentum of fluid is converted by centrifugal force into linear momentum by having a conduit take fluid away from the pump at the outermost edge of concentric passage.

Accelerator target holder* (2,670,440), Carroll M. Gordon, Charles A. Corum—Massive conically apertured wall flange is mounted adjacent to exit beam of accelerator. Intermediate flange plate, peripherally sealed with wall flange, is spaced to provide coolant chamber and outer cylindrically apertured flange plate.

Velocity modulated electronic supersonic generator† (2,671,213), Robert A. Rapuano—By means of this system for studying solid and fluid structure, charged-particle beam is directed to a plate resonant at predetermined supersonic frequency; beam density may be modulated at the supersonic frequency.

Pressure regulator* (2,672,154), William B. Leslie, Orear K. Neville—This pressure regulator for closed chemical reaction vessel comprises tubular container formed of two hollow sections connected by rubber coupling and held in angular position by adjustable clamp. One end of regulator is attached to reaction vessel; when pressure causes liquid to be forced out regulator, other section is raised or lowered to balance pressure.

Reaction and separation vessel* (2,672,404), Rudolph C. Schultz—Apparatus for reaction mixture of solids and liquids houses wall scrapers on motor-driven verticle shafts and scrapers on stationary shafts. Scrapers are shaped to scrape adjacent scrapers.

Electronic timing device* (2,672,556), Robert B. Leighton—Timer comprises tone generator, pair of bias generators for impressing separate negative and positive potentials on tone generator, storage network having selected period and means for impressing negative impulse on network. Network is connected to second bias generator for inactivating it for selected interval after actuation of other bias generator. Timer may be used in geophysical prospecting by means of spaced charges.

* Administered by Chief, Patents Branch, Atomic Energy Commission, Washington 25, D. C.

† Administered by Patent Counsel, Department of the Navy, Washington 25, D. C.

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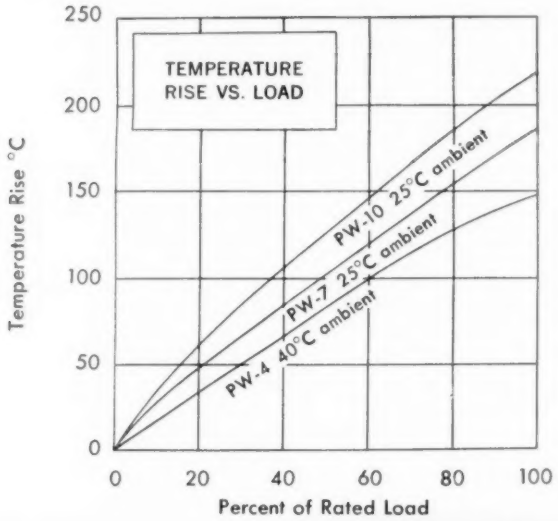
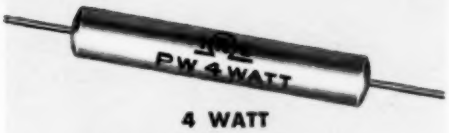
IRC's new power wire wounds are lower cost per watt than any other power type. At 4, 7 and 10 watts, they offer savings of several cents each in any application requiring compact, low cost, efficient power resistors. Types PW-4, PW-7 and PW-10 resistors assure safe operation in circuits where stability and low wattage dissipation are needed.





4 WATT

Type PW-4 allows safe operation with hot-spot temperatures up to 165°C. Fully insulated housing will not burn or support combustion.

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Types PW-7 and PW-10 allow safe operation with hot-spot temperatures up to 275°C.

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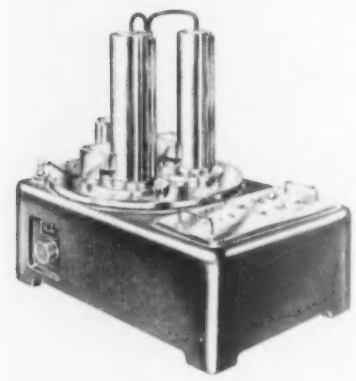
PRODUCTS AND MATERIALS

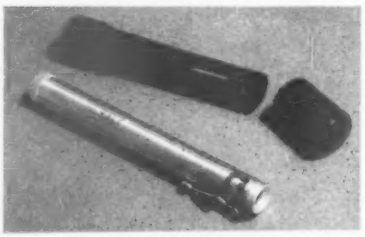
Isotope Carrier

The model 3035E 20-lb shielded isotope carrier, for bottled radioisotopes, is closed with a key-operated locking mechanism to prevent unauthorized personnel from handling the isotope. A bottle containing the isotope is lowered into the well of the shield where it is surrounded by 1 in. of lead. Spring platform raises the bottle when the lock at the top of the shield is removed. *Nuclear Instrument and Chemical Corp., 229 W. Erie St., Chicago 10, Ill.* (P-1)



Automatic Flow Counter

This automatic flow counter, completely sealed, accommodates up to 25 samples and makes it possible to obtain automatic radioassays with a windowless G-M or proportional counter. Unit keeps samples under gas flow at all times and accepts samples up to $1\frac{7}{8}$ in. in diameter and $\frac{5}{16}$ in. high. Instrument may be set to repeat counting cycle one, two or three times or indefinitely. Any desired number of samples may be by-passed and the index advanced accordingly. Radioassay results are printed on SC-5D Tracergraph tape, along with the sample number, in terms of elapsed time for the predetermined number of counts measured by the scaler. SC-18 or SC-51 scaler may be used with the counter. Accuracy is approximately 1%; resolving time is approximately 150 μsec for Geiger counting and is limited only by the resolving time of the scaler and/or amplifier for proportional counting. *Tracerlab, Inc., 130 High St., Boston 10, Mass.* (P-2)



Direct-Reading Dosimeter

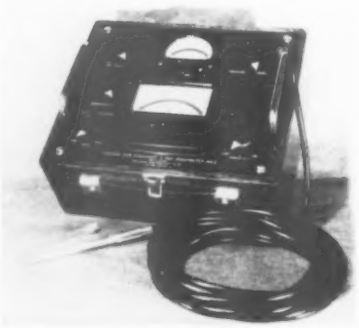
This watertight, low-cost dosimeter may be ordered for any range or scale between 5 and 100 r. Energy dependence is substantially zero down to 250 kev and 20%, max., down to 80 kev. Dosimeter is charged with battery pocket charger and fits standard British Civil Defense chargers; it can be adapted to any specified charger. Rubber jacket is available. *M. B. L. E., 80 Rue des Deux Gares, Brussels, Belgium.* (P-3)

Sine-Cosine Potentiometer

The model 106 sine-cosine potentiometer operates on both a-c and d-c and is said to be the smallest packaged potentiometer produced that performs sine-cosine functions at high-impedance levels. Potentiometers may be ganged on a common shaft to produce two electrically independent sine-cosine functions simultaneously. *Computer Instruments Co., 1964 Utica Ave., Brooklyn 34, N. Y.* (P-4)

Beta Thickness Gage

The model S beta thickness gage enables measurement of continuous-sheet-process industries where rate of production is low or production is intermittent. The unit permits thickness measurements of sheets up to 24 inches wide. Maximum weight per unit area that can be measured is 600 mg/cm²; minimum that can be presented full scale is 6 mg/cm². Basic unit has a standard time constant response of 0.5 sec; other time constants are available. Radiation source is strontium-90 unless otherwise specified. Accuracy of the unit, depending on application and operator's skill, is said to be better than 1% in some cases. Optional features, such as sheet-traversing mechanism, averaging and recording, are also available. *Industrial Nucleonics Corp., 1205 Chesapeake Ave., Columbus 12, Ohio.* (P-5)



X-Ray Dosimeter

The portable ionization-type Farmer dosimeter is said to be accurate over an X-ray energy range of 50–400 kv. The instrument is calibrated against a built-in primary standard. Probe-type ionization chamber may be connected to unit by a 10-ft cable. Readings can be made without switching

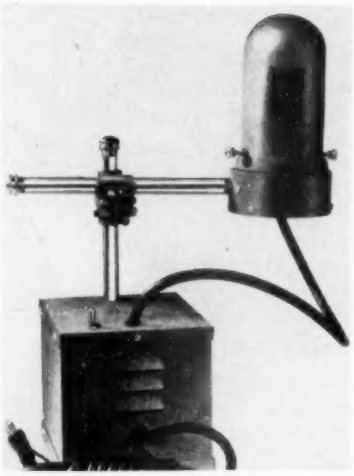
off X-ray source since the ionization chamber can be charged and discharged through the cable at any instant by means of switches on the instrument. *Baldwin Instrument Co., England (U. S. distributor: Atomic Center for Instruments and Equipment, Inc., 489 Fifth Ave., New York 17, N. Y.).* (P-6)

Fast-Neutron Counters

These fast-neutron counters are single and multichamber, directional and nondirectional. Counters of one, two and three chambers are filled with pure methane gas to a pressure of 150 cm and operate at 2,100 volts. Counters with more than three chambers are filled to a pressure of 13.2 cm and operate at 1,200 volts. In conjunction with an A1C amplifier having a bandwidth setting of 0.5 Mc and a gain of 5,000, discrimination is obtained between γ-rays and recoil protons. Gamma radiation is biased out completely at a pulse-height setting of 10 volts. Each chamber is lined with $^1/_{16}$-in. polyethylene and is separated from its neighbor by $^1/_{10}$-in. brass spacer to reduce gamma pile-up effect. *Radiation Counter Laboratories, Inc., 5122 W. Grove St., Skokie, Ill.* (P-7)

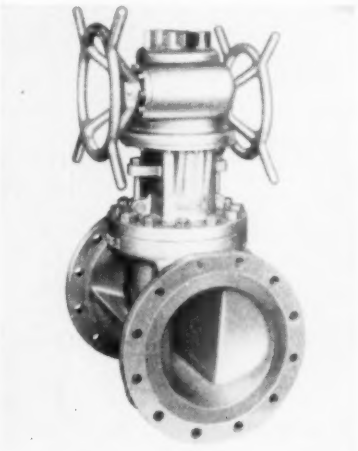
Pulse Amplifier

This pulse amplifier discriminator is suited to all forms of proportional and scintillation counting. Gain variable in 2-db steps from 200 to 20,000 times is available, together with control of integration and differentiation time constants for optimum signal-to-noise ratio. Discriminator section of unit has range of 5–50 volts. Regulated power supply is incorporated in the equipment. *Labgear (Cambridge) Ltd., Willow Pl., Cambridge, England.* (P-8)



Monochromatic Source

The model KLA-5C potassium laboratory are furnishes monochromatic light of potassium for polarimetry, interferometry, refractometry and spectrometry. It is suitable for general work in chemical and physical laboratories, and can supply strong red-line radiation with approximately 97% of the energy in the region of 7,699–7,765 Å. Other line radiations can be filtered out. *George W. Gates & Co., Inc., Hempstead Turnpike & Lucille Ave., Franklin Sq., N. Y.* (P-9)

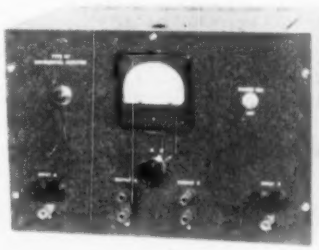


Plug Valve

This balanced-type plug valve is intended for refinery and general service involving high and low temperatures. The valves are gland packed; packings can be changed under pressure while the line is on stream. The plug valves are currently being produced in ASA 150 and 300 lb classes and are available in carbon-steel and other materials. *Hamer Oil Tool Co., 2919 Gardenia Ave., Long Beach, Calif.* (P-10)

Counting-Rate Meter

The model CRM-550 counting-rate meter, designed for scintillation counting, can also be used with less sensitive Geiger or proportional counters and accommodations are provided for a 1-ma chart recorder. Linear amplifier has rise time of about 1 μsec and amplification of better than 1,000. Pulse height discriminator is adjustable from zero to 100 volts. Variable error of 1, 2, 5, 10 and 20% results in 25 response times ranging from 1.5 msec to 4 min. The unit features five scales from 25 to 10,000 counts/sec. High-voltage power supply is variable from 700 to 2,000 volts, regulated to 0.005% change in output voltage per 1-volt change in line voltage between 95 and 130 volts. *Nuclear Research and Development, Inc., 6425 Etzel Ave., St. Louis 14, Mo.* (P-11)



Differential Analyzer

The type 501 differential analyzer is a wide-band amplifier that converts a differential signal into a single-ended signal. Amplifier consists of two identical channels and an output voltmeter that indicates the output signal potential. Each channel has a high-differential-ratio amplifier stage and a balance-to-unbalance converter with

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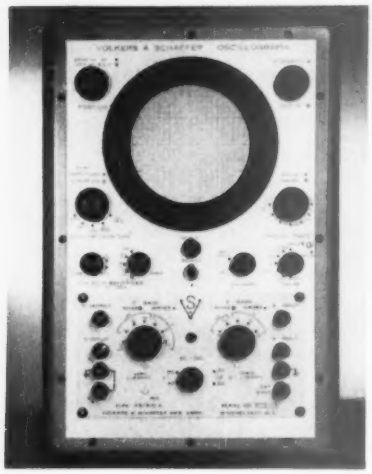
no transformer so that the degree of rejection of the common-mode signal can be made very high over a wide frequency range. The ratio of amplification for differential signals to that of common-mode signals is over 38 $\times 10^6$ from 8 cycles to 1 Mc; voltage amplification is approximately 30. Input impedance is 2.7 megohms shunted with 15 $\mu\mu$f from any input terminal to ground, and 5.4 megohms shunted with 10 $\mu\mu$f between the two off-ground terminals. Output impedance is approximately 300 ohms. *Advance Electronics Co., Inc., 451 Highland Ave., Passaic, N. J.* (P-12)



Oscillograph

The series VS-900 oscillograph has a d-c sensitivity of 700 μv/cm and an a-c sensitivity of 10 μv/cm; d-c drift, after a 5-min. warmup period, seldom exceeds 1 mv. The frequency range has an upper limit of 500 kc (3 db down); the response can be narrowed to 100, 50, 5 or 1 kc. *Volkers & Schaeffer Mfg. Corp., 1679 Broadway, Schenectady 6, N. Y.* (P-13)

Sine-Cosine Potentiometer

The RL11C sine-cosine potentiometer is wire wound and provides two output voltages accurately proportional to the sine and cosine of the angle of shaft rotation. The potentiometer has a 360-deg continuous mechanical rotation, a winding resistance of 16,000 ohms $\pm 10\%$ rated at 1.5 watts at 65° C, and a life expectancy of 350,000 revolutions. Sine and cosine outputs have average deviation $< 0.5\%$. *Rawson Electrical Instrument Co., 110 Potter St., Cambridge, Mass.* (P-14)

Temperature Indicator

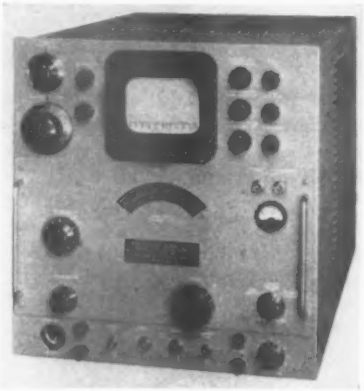
These temperature indicators are available in the following models: model 196, providing six overlapping ranges from −70 to +60° F; model 197, six overlapping ranges from +10 to +140° F; and model 198, which has a single range from +60 to +90° F. Sensing units are hand-calibrated thermistor pairs, which can be located 800 ft from the instrument with standard calibration or 8,000 ft with special calibration. The unit is battery operated; direct-reading accuracy is said to be ±0.5° F. *Beckman and Whitley, Inc., 974 E, San Carlos, Calif.* (P-15)

Vacuum Mixer

The Stir-O-Vac was designed for metal dispersions, solid-liquid reactions where shearing action is necessary and liquid-liquid reactions where reagents are not mutually miscible. The unit operates at speeds up to 20,000 rpm and vacuums down to 2 mm without the use of mercury seals. Seal is made through a special double-V Teflon washer. The mixer has a built-in cooling jacket around the oilless bearing. It can be driven by air or a series-wound electric motor. *Labline, Inc., 217–221 N. Desplaines St., Chicago 6, Ill.* (P-16)

Protective Coating

Two types of Magic-Vule vinyl protective coatings, applied by brush, spray gun or dipping, are available for abrasive and corrosive protection for metal, wood, concrete, fabric, etc. The coatings, vinyl resin-pigment-solvent or vinyl plastisol, dry to a tough, flexible finish. *Magic Chemical Co., 121 Crescent St., Brockton 2, Mass.* (P-17)



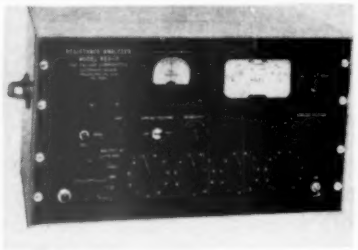
Spectrum Analyzer

The model TSA spectrum analyzer covers the range of 10–22,000 Mc with three interchangeable r-f heads. A single-dial, direct-reading, r-f tuning control is used to select the desired frequency spectrum. A swept i-f gives a frequency dispersion-range of 250 kc to 25 Mc with a resolution of 25 kc. An internal marker is provided to measure frequency differences up to ±12.5 Mc on a 5-in. crt display, with the frequency difference read directly on a calibrated control. The sensitivity of the TSA is said to be better than −80 dbm. An r-f attenuator is included to accommodate larger signals. *Polarad Electronics Corp., 100 Metropolitan Ave., Brooklyn 11, N. Y.* (P-18)

Diaphragm Seal

These diaphragm seals, designed for use in pressure gages, provide corrosion and clogging protection and make it possible to change or service the pressure instrument without disturbing production. A machined shape is employed to serve as a limit stop for the

diaphragm when the gage is removed and an integral piston moves the diaphragm back into operating position when the gage is replaced. It is claimed that the accuracy of the instrument is not affected by the removal and replacement of the instrument under process pressure. Diaphragm seals can be supplied in several alloys for corrosion protection and can be provided to operate at temperatures up to 500° F. *Mansfield & Green, 1051 Power Ave., Cleveland 14, Ohio.* (P-19)



Resistance Analyzer

The model KED-13 measures resistances of 1,000 ohms to 111 megohms to within ±0.1% and the voltage coefficient of any resistor, having up to 1.5-watt capacity, can be determined down to 0.0002%/volt. Voltage across the measured resistance is continuously variable, in two ranges, from zero to 500 volts by a self-contained regulated power supply. Sensitivity of balance is within 0.04% on all ranges. *The Kuljian Corp., Electronics Div., Philadelphia, Pa.* (P-20)

Recording Oscillograph

The 26-trace type 5-114 recording oscillograph has 45–115 in./sec record-speed range to record phenomena from static conditions to 3,000 cps. Timing lines photographed simultaneously with the data provide positive time correlation at 0.1 and 0.01 sec, or at 0.1-sec intervals only. Reference trace markers are provided as base lines for measuring trace amplitudes. Each oscillograph is equipped with a detachable 125-ft record magazine, unexposed-

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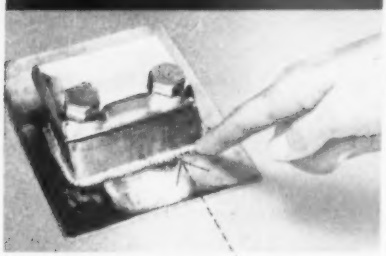

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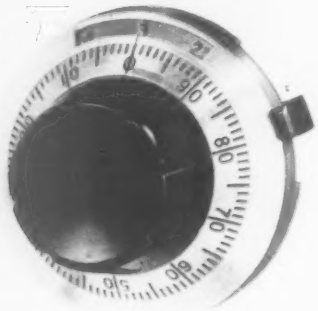
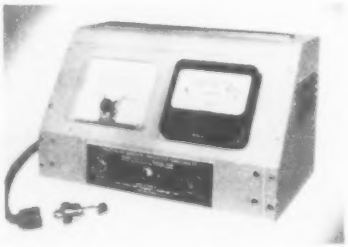
footage indicator, no-record warning device, record-length selector, heated magnet block and individual galvanometer-input connectors. *Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 8, Calif.* (P-21)



Rotation Counter

The RB series dial is used in electrical, mechanical, hydraulic and pneumatic applications to count the turns of rotating equipment to 0.01 turn. The unit consists of two coaxial dials and black nylon knob integral with the inner dial, which is calibrated to count hundredths of each turn. The outer dial counts the number of complete turns, up to 15. The unit is fastened on the shaft of the rotating component and can be rotated by either the shaft or the knob, and so can be used to set to a desired value as well as count power-driven turns. *Helipot Corp., S. Pasadena, Calif.* (P-22)



Vacuum Indicator-Controller

This vacuum indicator-controller automatically maintains a vacuum system in any preset range between 1 and 1,000 microns of mercury. The unit provides upper and lower limit control and an automatic reset, and may also be used to operate an alarm when the vacuum changes to either the upper or lower limit. *Hastings Instrument Co., Hampton, Va.* (P-23)

Vacuum Tube Voltmeter

The MV-17C d-c millivoltmeter has 13 scales ranging from 0–1 mv to 0–1,000 volts with input impedances of 6–60 megohms. The accuracy of the instrument is ±3% of full scale. The voltmeter obtains good stability with a semidirect-coupled "starved" amplifier circuit having a high negative feedback ratio. *Millivac Instrument Corp., 444 Second St., Schenectady 6, N. Y.* (P-24)

Pulse Transformers

The miniature type 10Z transformers were primarily engineered for use in flip-flop, buffer, pulse-amplifier and gating circuits with pulse durations from 0.1 to 0.5 μsec. The larger type 20Z transformers are designed for blocking oscillators, push-pull memory-ring drivers and other applications requiring fast rise time with minimum pulse lag and decay and widths up to 20 μsec. *Sprague Electric Co., 259 Marshall St., N. Adams, Mass.* (P-25)

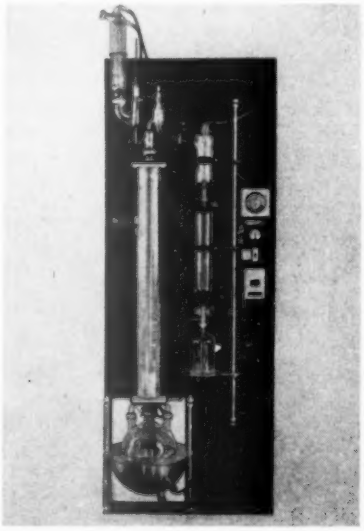
Pyrometer

The series 4530 automatic pyrometer is an on-off control for furnaces, ovens and other equipment where temperature must be held by turning heat off and on. It is a thermocouple millivoltmeter with adjustable contacts and load relay rated at 5 amperes, 125 volts a-c. Higher load ratings can

be furnished. Switch can be set to hold the temperature or to shut off when preset temperature is reached. Range is 500–1,500° F. *Assembly Products, Inc., Box 191, Chagrin Falls, Ohio.* (P-26)

Valves

Models 3460, Domotor-operated, and 3420, cylinder-operated, valves were designed for pressures to 6,000 psi and temperatures to 900° F. Valves are furnished in $\frac{1}{2}$ and $\frac{3}{4}$ in. sizes. *The Annin Co., 6570 E. Telegraph Rd., Los Angeles 22, Calif.* (P-27)



Fractionator

The Dalin distillation apparatus is available in a range of sizes and types for charges ranging from 2 ml to 72 liters. Standard columns can be supplied with boil-up rates as high as 30 liters/hr, depending on the diameter of the column and the packing. The

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columns, which are adiabatic, are heated by coiled-ribbon windings, for operation at temperatures up to 350° C. Thermometers are located within each winding to indicate the column temperature during preheat time. *Scientific Glass Apparatus Co., Inc., Bloomfield, N. J.* (P-28)

Delay Lines

The model 250, a true decade-delay line and not a tapped system, is designed for laboratory use. Characteristic impedance is 1,000 ohms; delay calibration tolerance is ±1%. This unit provides a maximum delay of 50.1 μsec in steps of 0.1 μsec and has a rise time of 2 μsec and 50% attenuation at maximum delay. Models are available with other delay characteristics. *ESC Corp., 578 E. 161st St., New York 56, N. Y.* (P-29)

Electric Meter

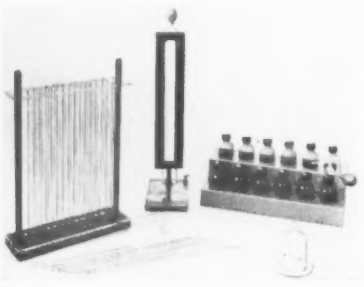
This meter movement incorporates a moving-coil suspension that is said to practically eliminate friction, zero drift and instability by eliminating difficulties associated with conventional movements. The new movement is claimed to withstand mechanical shocks of 500 G on all three axes and electrical overloads in excess 100,000%. *Greibach Instruments Corp., Metuchen, N. J.* (P-30)

Environmental Cabinet

The Weather-Lab is available in standard 20- and 30-ft³ sizes for simulation of most conditions between +35° F and +200° F, and between 20% and 95% humidity. Access to the test space is through two front-opening "reach-in" type doors. The basic unit is equipped with an exterior-mounted control panel with adjustable wet and dry bulb thermostats. *Refrigeration Systems, Inc., Hudson Bay Div., 646 W. Washington Blvd., Chicago 6, Ill.* (P-31)

RF Power Bridge

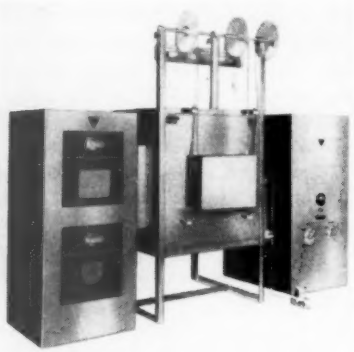
The model 302 VHF-UHF power bridge covers a frequency range of 10–1,000 Mc and is capable of measuring power levels from 2 μw to 30 mw in six ranges. The instrument has a balanced input impedance of 300 ohms and total error of less than 5%. Applications include measurements on tuners, converters, and transmission measurements of active and passive networks. *Electro-Metric Instrument Co., 241 Centre St., New York 13, N. Y.* (P-32)



Density Gradient Analyzer

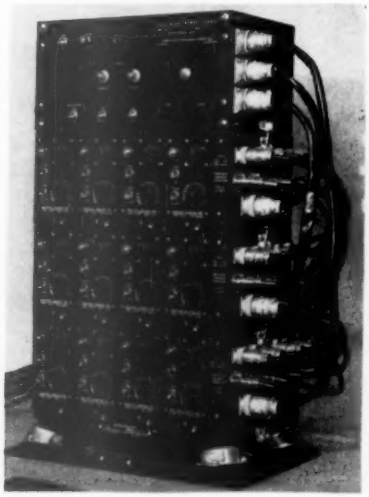
This density gradient analysis set is used to establish the identity or non-identity of origin between two objects or materials. It provides for comparative analysis of glass, soils, safe in-

sulation, sand rock, mineral materials and hair, and requires 25 mg or less of sample. The analyzing set contains a bottle rack, 11 density gradient liquids and bottles, glass tubes and stand, densitometer and a combination delivery and suction head. *Microchemical Specialties Co., 1834 University Ave., Berkeley 3, Calif.* (P-33)



Heat-Treating Furnace

The model FG-430 general-purpose heat-treating furnace includes temperature indication, control and permanent record, plus completely automatic time-temperature program control for the full heating and cooling range. The equipment operates at temperatures up to 2,700° F and is said to have an accuracy to within 0.25%. *Perény Equipment Co., 893 Chambers Rd., Columbus 12, Ohio.* (P-34)



Multichannel Amplifier

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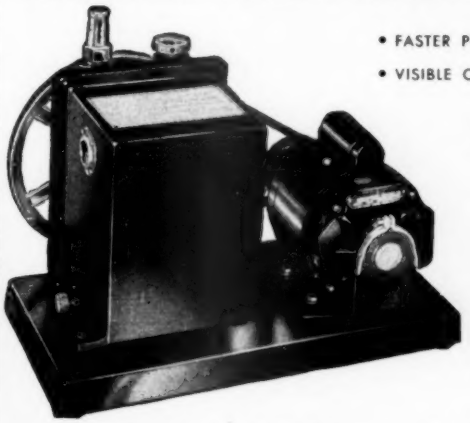

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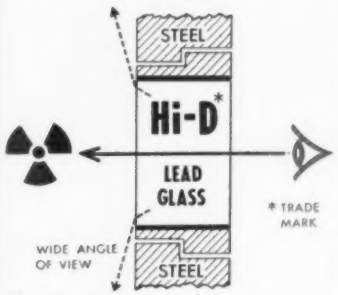

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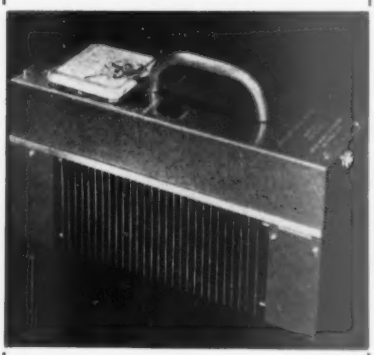

The toxic limit is a full scale reading on the high sensitivity scale of Model 23, illustrated above. The weight is 7 pounds and the size is 13 x 8¼ x 4¼ inches.

A bibliography on the mercury vapor hazard is available on request as well as literature on the different models of the Kruger Mercury Vapor Meter.

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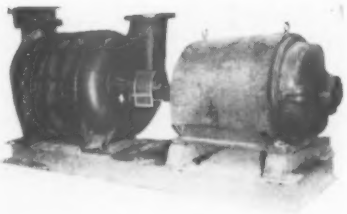
linear-integrating and carrier-amplifier units may be used in any combination up to a maximum of twelve to permit simultaneous use of self-generating and externally excited pickups. Physical phenomena in the 0–5,000 cps range may be amplified; output can be coupled to any recording oscillograph equipped with galvanometers of matched characteristics. The system may be used with capacitance, inductance, reluctance, resistance, piezoelectric and photoelectric transducers. Single record indicates strain, pressure, acceleration, vibratory displacement and velocity. *Consolidated Engineering Corp., 300 N. Sierra Madre Villa, Pasadena 8, Calif.* (P-35)

Power Supply

The model MR1040-30 magnetic amplifier d-c regulated power supply is rated at 10–40 volts at 30 amperes and has an accuracy of ±1% from 10–40 volts output, 3–30 ampere load and 100–130 volt line variation. The supply employs magnetic materials and low-leakage selenium rectifiers and contains no tubes. *Perkin Engineering Corp., 345 Kansas St., El Segundo, Calif.* (P-36)

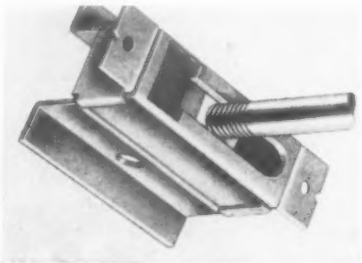
Infrared Water Bath

The model 12A infrared bath provides temperature control from 2 to 65° C. Temperature is normally held within 0.005° C, over the entire range. Continuously adjustable circulation is maintained by a centrifugal pump; connections are provided for externally circulating the temperature-controlled water. *Kinetic Instrument Co., Dept. 20, Highland Park, Ill.* (P-37)



Centrifugal Blower

The model 386 centrifugal blower can be factory assembled to deliver any air volume between 2,000 and 9,000 ft³/min with pressures ranging from 1 to 9 psig, or vacuum from 2 to 12 in. Hg. The units are self-adadpting to any variation in air-volume requirements from minimum to maximum capacity. The blower can be assembled from stock parts and custom-made for the particular application. *U. S. Hoffman Machinery Corp., 105 Fourth Ave., New York, N. Y.* (P-38)



Concrete Anchor

This concrete insert is designed for quick suspension of piping, electrical conduit, heating and ventilating ducts, etc., and supports up to 1,000 lbs. *Unistrut Products Co., 1013 W. Washington Blvd., Chicago 7, Ill.* (P-39)

Correction

The Red Dot series of point-contact germanium diodes, manufactured by International Rectifier Corp., 1521 E. Grand Ave., El Segundo, Calif., are manifestly not transistors, as reported in the May issue of NUCLEONICS.

INDUSTRY NOTES

▶**Applied Radiation Corp.,** 1210 Springbrook Rd., Walnut Creek, Calif., has been organized for the development of a new type of electron linear accelerator as its initial project. The 6-million-volt accelerator is claimed to be more powerful than the GE resonant transformer or the Van de Graaff and to be simpler, smaller, lighter and less expensive. It weighs about 2,000 lb

and requires space 4 × 4 × 9 ft and will sell for about $100,000. One application is expected to be in the food industry. Scientists concerned with its design and construction are M. R. Jeppson (company president), D. Garbellano (vice president and general manager), H. Gordon (second vice president), and R. Post.

▶**Vitro Uranium Co.,** Salt Lake City, Utah, division of Vitro Corp. of America, has received a 5-yr AEC contract for production of concentrate from uranium ores. New contract adjusts compensation for variations in ore content and process changes and provides for tonnage increase.

▶**Tracerlab, Inc.,** 130 High St., Boston 10, Mass., has been awarded Navy order for 9,000 self-luminous deck and personnel markers activated with Sr^{90}. These markers reduce radiation hazard to personnel and provide ten times the brightness (80 effective microlamberts) of Ra-excited markers.

LITERATURE AVAILABLE

Pressure transducer. Bulletin PT-1 describes transducers for the measurement of gage, differential or absolute pressures. *Statham Laboratories, Inc., 12401 W. Olympic Blvd., Los Angeles 64, Calif.* (L-1)

Industrial X-ray unit. Norelco MG 160 folder describes a portable self-contained industrial X-ray radiographic unit. *North American Philips Co., Inc., 750 S. Fulton Ave., Mount Vernon, N. Y.* (L-2)

Micromicroammeter. Bulletin discusses combining electrometer and decade shunt to produce micromicroammeter. *Keithley Instruments, 3868 Carnegie Ave., Cleveland 15, Ohio.* (L-3)

Electron accelerator. March 1954 bulletin describes accelerator for industrial, radiographic and therapeutic applications. *Applied Radiation Corp., 1210 Springbrook Rd., Walnut Creek, Calif.* (L-4)

Hose coupling. Booklet describes leak-proof quick-seal hose coupling. *Titeflex, Inc., Hendee St., Springfield 4, Mass.* (L-5)

Valve and pump packings. Bulletin TP-1053 describes Teflon valve and pump packings. *United States Gasket Co., Camden 1, N. J.* (L-6)

Laboratory ovens. Catalog 331 describes ovens, sterilizers, incubators

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and related equipment. *Precision Scientific Co., 3737 W. Cortland St., Chicago 47, Ill.* (L-7)

Distilled water safeguard. Bulletin 131 describes air filter for protecting distilled water in storage. *Barnstead Still & Sterilizer Co., 222 Lanesville Terrace, Boston 31, Mass.* (L-8)

Electronic components. Catalog R-200 describes resistors, deflection yokes coils, and transformers. *I-T-E Circuit Breaker Co., 19th and Hamilton Sts., Philadelphia 30, Pa.* (L-9)

Flow counter. Bulletin describes model 952 flow counter for Geiger or proportional counting. *Atomic Instrument Co., Cambridge 39, Mass.* (L-10)

Hydraulic servo. Bulletins 116-A and 118-A describe hydraulic servo actuator and transmission system. *Pegasus Laboratories, 3690 11 Mile Rd., Berkley, Mich.* (L-11)

Miniature inductor. April 1954 bulletin gives specifications of SL1 and SL2 miniature inductors. *Mico Instrument Co., 828 Towbridge St., Cambridge 38, Mass.* (L-12)

Raman spectrography equipment. Catalog CH334/2 illustrates line of recording and direct-reading equipment. *Jarrell-Ash Co., 26 Farwell St., Newtonville, Mass.* (L-13)

Temperature control. Bulletin 102 covers high-temperature safety alarms and cut-outs, models V-1C and V-1X. *Burling Instrument Co., Inc., 16 River Rd., Chatham, N. J.* (L-14)

Gages and valves. Data unit 237 covers special-purpose heated and cooled gages and valves. *Jergu son Gage & Valve Co., 80 Fellsway, Somerville 45, Mass.* (L-15)

Valves. Brochure describes series 50 safety valves. *Marine & Industrial Products Co., 1150 W. Marquette Blvd., Chicago 21, Ill.* (L-16)

Enclosed laboratory system. Catalog describes enclosed units for hazardous chemical, biological, and radiological work. *Kewaunee Mfg. Co., Adrian, Mich.* (L-17)

Freezing-point depression. Bulletin 2248 describes apparatus that permits cryoscopic osmotic-activity determinations of 1-cm³ aqueous samples. *American Instrument Co., Inc., Silver Spring, Md.* (L-18)

Vacuum tube voltmeter. Brochure describes model 400D for 10 cps to 4

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Mc. *Hewlett-Packard Co., 395 Page Mill Rd., Palo Alto, Calif.* (L-1)

Recording controller. Booklet GED-2100 describes potentiometric and a-c bridge recorders and recording controllers. *General Electric Co., Schenectady 5, N. Y.* (L-20)

Electrical instruments. Catalog N-1 lists meters and accessories. *Burlington Instrument Co., 153 N. Third St., Burlington, Iowa.* (L-21)

Precision potentiometers. Brochure describes the RVBC2 ball bearing potentiometer. *Servotrol Co., Framingham Centre, Mass.* (L-22)

Valves. Brochure illustrates stainless-steel safety and relief valves. *Associated Valve & Engineering Co., 1150 W. Marquette Rd., Chicago 21, Ill.* (L-23)

Titanium tubing. Bulletin 42 describes properties, applications and advantages of titanium tubing. *Superior Tube Co., 1552 Germantown Ave., Norristown, Pa.* (L-24)

A-C test set. Bulletin describes 60-cycle a-c test set. *Sensitive Research Instr. Corp., Dept. 170A, 9-11 Elm Ave., Mt. Vernon, N. Y.* (L-25)

Computers. "Light on the Future" explains organization of digital computers and describes functions of input, storage, arithmetic, control and output components. *International Business Machines Corp., 590 Madison Ave., New York 22, N. Y.* (L-26)

Chokes. Data on insulated chokes is given in bulletin H-1. *International Resistance Co., 401 N. Broad St., Philadelphia 8, Pa.* (L-27)

Galvanometer pens. Bulletin B-1 gives characteristics of ink-writing galvanometers for research and industrial use. *Edin Co., Inc., 207 Main St., Worcester 8, Mass.* (L-28)

Valves. Line of standard and custom-built valves for gas- and oil-heating applications, refrigeration, and air conditioning is described in "Solve These Flow Control Problems." *A-P Controls Corp., 2450 N. 32nd St., Milwaukee 45, Wis.* (L-29)

Water treatment. Bulletin 28X75-01A discusses types of cooling systems with problems of metal surface corrosion, inorganic scaling, organic growths and delignification of the wood in the tower, and gives information on the selection of chemical treatment. *Allis-Chalmers Mfg. Co., 1316 S. 70th St., Milwaukee, Wis.* (L-30)

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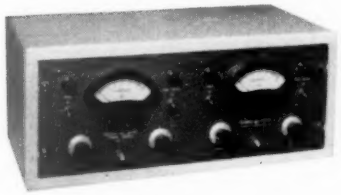

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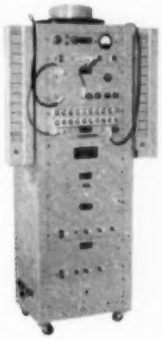

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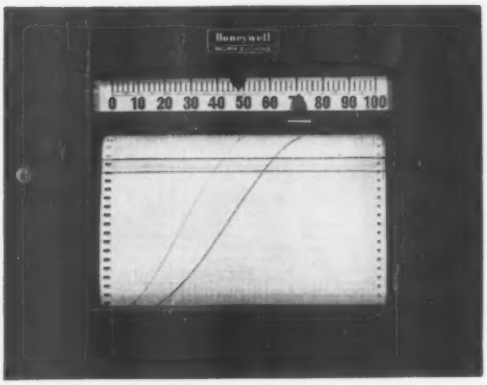

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